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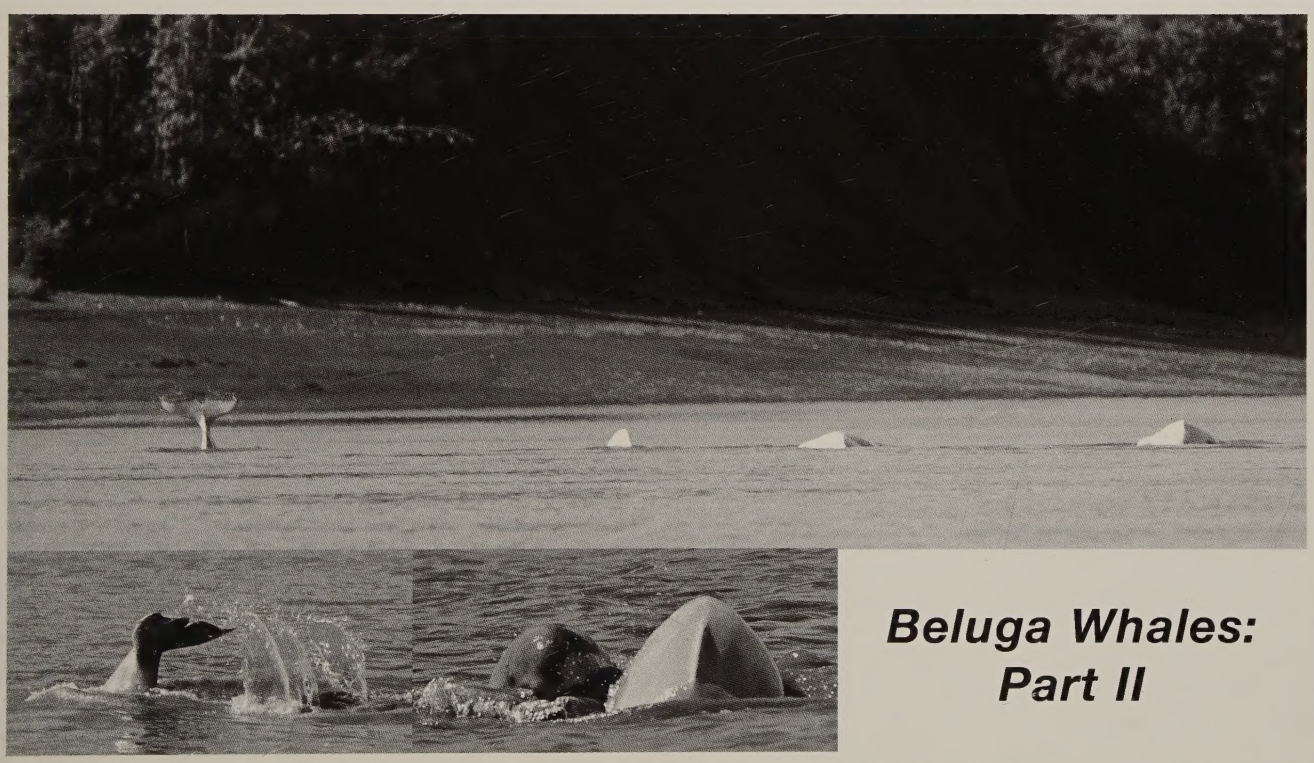

Beluga Whales: Part II

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On the cover:
Beluga whales, *Delphinapterus leucas,* in Cook Inlet, Alaska. Top photo taken from shore, courtesy of Chris Garner, U.S. Army, Joint Base Elmendorf-Richardson, and bottom photos courtesy of LGL Alaska Research Associates, NMFS General Authorization LOC 481-1795-01 and MMPA-ESA research permit 14210.

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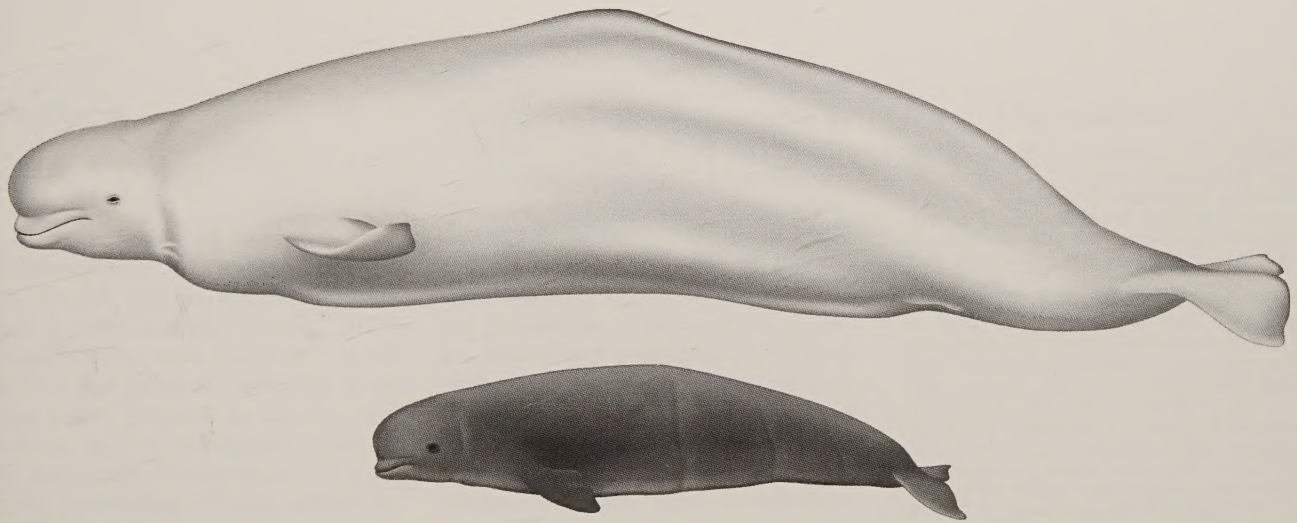

Beluga whale, *Delphinapterus leucas*. Illustration by Uko Gorter.

The Status of Beluga Whales, *Delphinapterus leucas*, in Cook Inlet, Alaska, and Surrounding Waters: Part II

Preface

In "The Status of Beluga Whales, *Delphinapterus leucas*, in Cook Inlet, Alaska, and Surrounding Waters: Part I (Shelden and Hobbs, 2015), seven papers were published in the first of two volumes dedicated to beluga whale research in Alaska, with a focus on the endangered Cook Inlet population. It had been 15 years since publication of the special issue on beluga whales in the *Marine Fisheries Review* 62(3), at that time featuring the depleted Cook Inlet population. *Marine Fisheries Review* 77(1) includes an update of the Cook Inlet abundance and trend time series through 2012 (Hobbs et al., 2015), a synopsis of Alaska beluga whale prey based on stomach content analyses (Quakenbush et al., 2015), an ethogram for wild beluga whales based on studies at Eagle Bay in Cook Inlet (Howe et al., 2015), three papers on the Yakutat Bay belugas, a small breeding group that is genetically distinct from Cook Inlet (Castellote et al., 2015; Lucey et al., 2015; O'Corry-Crowe et al., 2015), and a novel beluga monitoring project conducted on the Little Susitna River in Cook Inlet (Polasek et al., 2015).

This second issue is dedicated exclusively to Cook Inlet studies and includes a review of spatio-temporal changes in beluga distribution, a population viability analysis and extinction risk assessment, a summary of potential natural and anthropogenic risks, a calf index, a citizen science project, a note on socio-sexual behavior, and beluga behavioral responses observed during Port of Anchorage monitoring studies. We hope these contributions generate discussion on future research and management needs for this unique species.

This concludes the two part series but by no means is the end of the story. We are aware of a number of studies currently in progress within Cook Inlet, including, but not limited to, photo-identification, acoustic monitoring, stranding response, and the biennial abundance survey planned for June 2016. These studies, and the studies presented herein in *Marine Fisheries Review* 77(1) and 77(2), provide valuable information to meet our mandate for protecting this endangered species.

By Kim Shelden and Rod Hobbs

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Spatio-temporal Changes in Beluga Whale, *Delphinapterus leucas*, Distribution: Results from Aerial Surveys (1977-2014), Opportunistic Sightings (1975-2014), and Satellite Tagging (1999-2003) in Cook Inlet, Alaska

KIM E.W. SHELDEN, KIMBERLY T. GOETZ, DAVID J. RUGH,
DONALD G. CALKINS, BARBARA A. MAHONEY, and RODERICK C. HOBBS

Introduction

The waters of Cook Inlet, Alaska, are occupied year-round by a small, distinct population of beluga whales, *Delphinapterus leucas* (Fig. 1). One of the earliest descriptions of this population's distribution within Cook Inlet is found in Cornelius Osgood's 1933 account from an ethnological expedition undertaken in 1931:

> "Of the sea-mammals used for food, fur, or both (hair-seal, ground-seal, sea-otter, sea-lion, porpoise, beluga and whale) which were found in the Lower inlet, only two (hair-seal and beluga) were found elsewhere, that is, in the Middle inlet and seasonally in the Upper inlet" (p. 697).

Aerial surveys using fixed-wing aircraft were introduced in Alaska in the 1930's to assess wildlife populations (Eicher, 1953; Jones et al., 2007). The first aerial surveys to estimate beluga whale numbers were conducted in 1954 in Bristol Bay, Alaska (Brooks[1]). Investigations by the Alaska Department of Fisheries were primarily in response to concerns expressed by commercial fishermen about beluga predation on Pacific salmon, *Oncorhynchus* spp. (Brooks[1]). The Alaska Department of Fish and Game (ADFG) flew the first aerial surveys to enumerate the Cook Inlet beluga whale (CIBW) population in the 1960's (Klinkhart[2]). According to Edward Klinkhart[2],

> "Aerial surveys of Cook Inlet which I made in 1963 and 1964 indicated a summer population of 300 to 400 animals" (p. 3).

The information was limited, however, as Klinkhart[2] did not include a map or any descriptions of where or exactly when surveys took place during those summers.

In the 1970's, increasing interest in petroleum development throughout Alaska waters led to the National Oceanic and Atmospheric Administration (NOAA) funding large-scale, systematic surveys to determine seasonal distribution of seabirds and marine mammals. The Outer Continental Shelf Environmental Assessment Program (OCSEAP[3]) large-scale surveys of the Gulf of Alaska included aerial surveys of mid-inlet waters in lower and central Cook Inlet (primarily south

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doi: dx.doi.org/10.7755/MFR.77.2.1

[1]Brooks, J. W. 1954. Beluga. *In* Annual Rep. for 1954, Alaska Dep. Fish., Juneau, p. 51–57, and Brooks, J. W. 1955. Beluga. *In* Annual Rep. for 1955, Alaska Dep. Fish., Juneau, p. 98–106.

[2]Klinkhart, E. G. 1966. The beluga whale in Alaska. Alaska Dep. Fish Game, Juneau, Fed. Aid. Wildl. Restor. Proj. Rep. Vol. VII, Proj. W-6-R and W-14-R, 11 p.

[3]OCSEAP documents (avail. at http://www.arlis.org/docs/vol1/OCSEAP2/).

ABSTRACT—Cook Inlet is inhabited year-round by a small, distinct group of beluga whales, Delphinapterus leucas. *This endangered and declining population lives near Anchorage, the largest city in Alaska, and waterways frequented by fishing fleets, container ships, oil-gas development, air traffic, and military operations. Their summer distribution has been well-studied but in winter and early spring the combination of poor sighting conditions (low light levels, white whales among ice floes) and whale behavior (close association with ice, longer, deeper diving patterns, smaller groups) made detection difficult. Based on our review of beluga presence data from aerial surveys, satellite-tagging, and opportunistic sightings, their range has contracted remarkably since the 1990's. Almost the entire population is found in only northern waters from late spring through the summer and into the fall. This differs markedly from surveys in the 1970's when whales were found in or would disperse to the lower inlet by midsummer.*

By early June, belugas now gather at river mouths in the Susitna Delta and Chickaloon Bay. Since the Endangered Species Act listing decision in 2008, 83% of the total population now occupies the Susitna Delta in early June compared to roughly 50% in the past. In August, sightings increase in Knik Arm, with some dispersal to deeper upper inlet waters. In fall, belugas disperse south though few whales are found in the lower inlet. In winter, belugas now occur in the upper inlet and make occasional visits to the lower inlet, and there is no evidence of migration out of Cook Inlet. The population appears to now be consolidated into preferred habitat in the upper-most reaches of Cook Inlet.

Figure 1.—Place names in Cook Inlet, Alaska, mentioned in the text. Tidal mudflats (shaded areas) and the 10 m isobath are shown. The upper inlet is defined as waters north of East Foreland and West Foreland, the lower inlet includes all waters south of these Forelands, mid-inlet waters are defined as those deeper than the 10 m isobath (excluding bays).

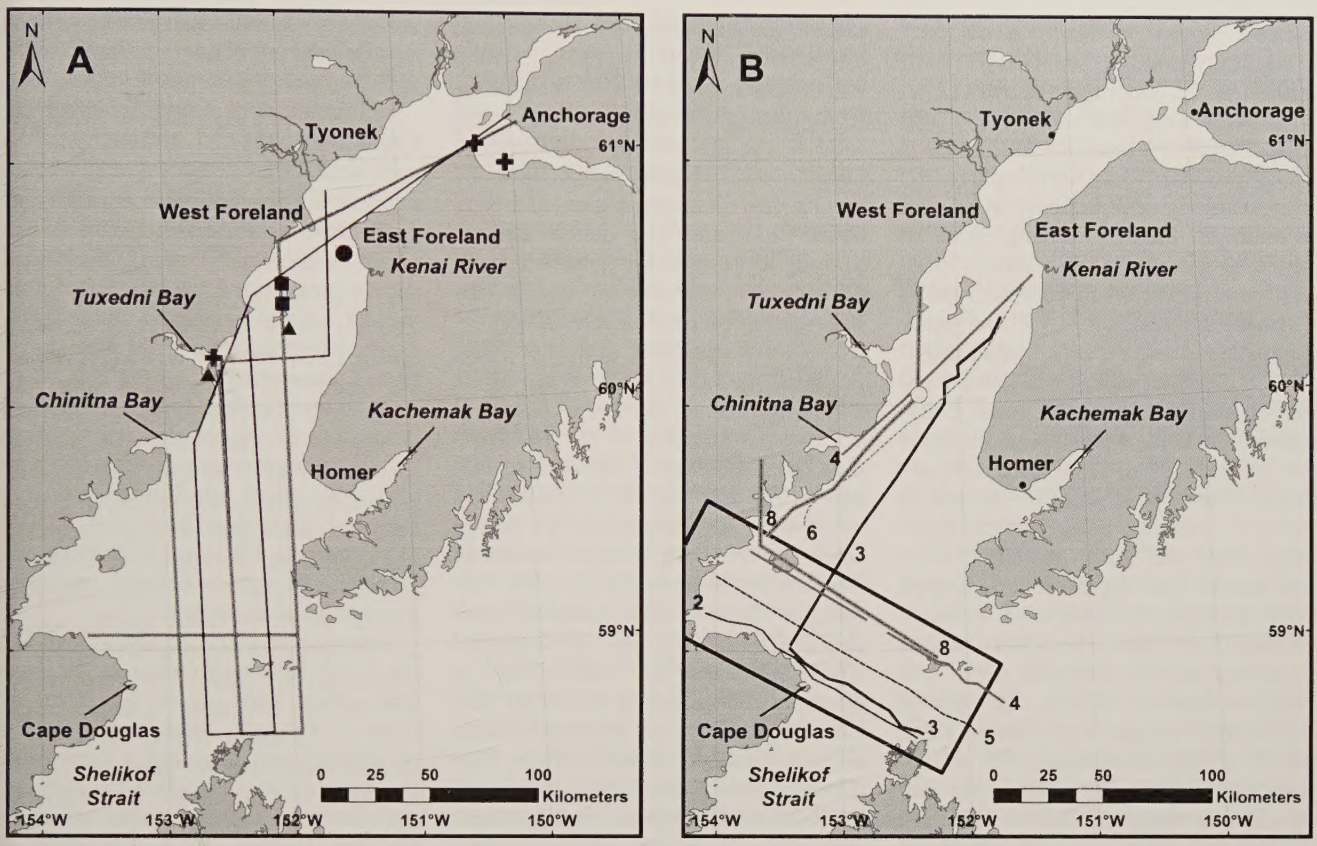

Figure 2.—Beluga whale sightings and survey effort in Cook Inlet, Alaska, from A) Harrison and Hall (1978) in 1975: October (squares, group sizes = 1 and 3); and 1977: March (triangles, group sizes = 1 and 3), April (pluses, group sizes = 1); and June (circle, group size = 20); and B) Leatherwood et al. (text footnote 4) showing Survey Block 7, Zone 1 as the box north of Shelikof Strait. Only surveys with effort collected north of Cape Douglas were plotted and are identified by number as: 2 (May–June 1982), 3 (July 1982), 4 (Aug. 1982), 5 (Sept. 1982), 6 (Oct.–Nov. 1982), and 8 (Feb.–Mar. 1983). The lone group of five belugas (circle shown mid-inlet east of Tuxedni Bay) was observed during a survey 8 on-effort training segment.

of East and West Foreland) during the mid- to late 1970's (Harrison and Hall, 1978) and early 1980's (Leatherwood et al.[4]). Only a few belugas were observed during these surveys (Fig. 2). The paucity of sightings was likely due to the survey design, which did not include coastal waters within the inlet. Leatherwood et al.[4] noted:

> "Belugas were also observed repeatedly in the Cook Inlet complex during our transit flights into and out of Anchorage, particularly near the estuary of the Kenai River" (p. 312).

An OCSEAP study that originally focused on Steller sea lion, *Eumetopias jubatus*, investigations in the Gulf of Alaska (Calkins and Pitcher[5]) was "expanded to include an examination of the distribution and abundance of belukha whales (*Delphinapterus leucas*) in Cook Inlet" (p. 146). This first attempt to thoroughly document CIBW seasonal distribution using aircraft occurred in the late 1970's (Murray[6]; Murray and Fay[7]). Under the direction of ADFG, aerial surveys were conducted in Cook Inlet from November 1977 through August 1979.

ADFG resumed aerial surveys in the early 1980's as part of the Susitna Hydroelectric Project funded by the

[4]Leatherwood, S., A. E. Bowles, and R. R. Reeves. 1983. Aerial surveys of marine mammals in the southeastern Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 42(1986):147–490 (avail. at http://www.arlis.org/docs/vol1/OCSEAP2/authorindex.html and accessed 16 June 2011).

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[7]Murray, N. K., and F. H. Fay. 1979. The white whales or belukhas, *Delphinapterus leucas*, of Cook Inlet, Alaska. Pap. SC/31/SM12 pres. to IWC Sci. Committee, June 1979, 7 p.

Alaska Power Authority (Calkins[8]). This study documented CIBW distribution in the upper inlet (north of East and West Foreland) during the ice-free season to assess potential impacts from proposed dam development on the Susitna River. Summary maps, and sometimes tables, showing seasonal sighting data from these ADFG studies were presented in contract reports (Murray[6], Calkins[8, 9, 10]) but never published in a peer- reviewed journal.

The Alaska Fisheries Science Center's National Marine Mammal Laboratory (NMML) received photocopies of some of the original field logs and maps from these ADFG studies in 1999.[11] Initially, beluga whale sightings from the June and July flight summaries were digitized and mapped, and subsequently compared to whale distributions from National Marine Fisheries Service (NMFS) aerial surveys conducted during the period 1993–2008 (Rugh et al., 2010). Rugh et al. (2010) documented a significant northward contraction in the early summer range of CIBWs since the 1970's. In 2012, all available tracklines and sightings from the 1977–79 and 1982–83 surveys were scanned and digitized to update the CIBW Opportunistic Database maintained by NMML (Vate Brattström et al.[12]). We present the ADFG survey methods and effort in Appendix 1 (1977–79) and Appendix 2 (1982–83)[13] transcribed from the original field notes and maps.

After the ADFG surveys, distribution studies did not resume until the 1990's. NMFS began dedicated CIBW distribution and abundance surveys in June 1991 (NMFS[14]; Shelden and Mahoney[15]). Subsequent aerial surveys during the period 1993–2014 focused on distribution and abundance primarily in June (Rugh et al., 2000, 2005; Shelden et al., 2013, Hobbs et al., 2015a; Shelden et al.[16]). NMFS also conducted aerial surveys in August from 2005 to 2012 specifically to look at the proportion of beluga calves in the northernmost waters of Cook Inlet (Hobbs et al., 2015b). Additional months were sampled from July 2001 to April 2002 to document CIBW numbers and distribution in other seasons (Rugh et al., 2004). The U.S. Department of Interior, Minerals Management Service (MMS, now the Bureau of Ocean Energy Management (BOEM)) also flew beluga whale distribution surveys during February and March of 1997 (Hansen and Hubbard[17]). Using these datasets, we compared CIBW distribution across months and years from the late 1970's to 2014.

In 1999, NMFS began capturing CIBWs during the summer months and attaching satellite-linked time-depth recorders to their dorsal ridges (Ferrero et al., 2000; Hobbs et al., 2005; Goetz et al.[18]). In all, 18 belugas were captured and tagged during this project which continued until 2002. Some of these tagged whales transmitted locations during the fall, winter, and spring; therefore, we included these data to supplement the sighting data, particularly for months when aerial survey effort was limited. We also included sightings from the CIBW Opportunistic Database to provide additional, though anecdotal, insights into beluga distribution.

Attempts to estimate abundance for the Cook Inlet population in the past have often been based on observations of a single, large concentration of animals and applying a correction for surface intervals when animals are not visible beneath the turbid waters in the inlet (Hazard, 1988). The listing of CIBWs on the List of Candidate Vertebrate and Invertebrate Marine Species under the U.S. Endangered Species Act in 1988 (NOAA, 1988) was, in part, based on abundance estimates from these studies which suggested at minimum about 500 whales (Hazard, 1988). Calkins[10], reporting on Murray's aerial survey findings (Appendix 1), noted:

> "In subsequent aerial survey/sighting combinations, the highest minimum direct count I have obtained for a single day was 479 animals [*sic.* 473 in Appendix 1] on 21 August 1979. Some investigators have speculated that three times as many whales are pres-

[8]Calkins, D. G. 1984. Belukha whale. Vol. IX of Susitna hydroelectric project; final report; big game studies. Alaska Dep. Fish Game., Doc. 2328, 17 p. (avail. at http://www.arlis.org/docs/vol1/Susitna/23/APA2328.pdf and accessed 4 Mar. 2015).

[9]Calkins, D. 1983. Marine mammals of lower Cook Inlet and the potential for impact from outer continental shelf oil and gas exploration, development, and transport. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 20:171–263 (avail. at http://www.arlis.org/docs/vol1/OCSEAP2/Final/6515301/F%20v20.pdf and accessed 4 Mar. 2015).

[10]Calkins, D. G. 1989. Status of belukha whales in Cook Inlet. *In* L. E. Jarvela and L. K. Thorsteinson (Editors), Proceedings of the Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information Update Meeting, Feb. 7–8, 1989, Anchorage, Alaska, p. 109–112. OCS Study MMS 89-0041, U.S. Dep. Inter., Bur. Land. Manage., Minerals Manage. Serv.

[11]Courtesy of Kenneth W. Pitcher, Alaska Dep. Fish. Game, Anchorage, 15 June 1999.

[12]Vate Brattström, L., C. Sims, R. Hobbs, and B. Mahoney. 2010. The Cook Inlet beluga whale opportunistic database: A summary of opportunistic sightings during the past 35 years. Poster pres. at Alaska Mar. Sci. Symp., Anchorage, AK, Jan. 2010 (avail. at http://access.afsc.noaa.gov/pubs/posters/pdfs/pVate-Brattstrom01_cook-inlet-beluga-db.pdf and accessed 22 Jan. 2014).

[13]Appendices are available in the online version of this article (doi: 10.7755/MFR.77.2.1).

[14]NMFS. 1992. Status report on Cook Inlet belugas (*Delphinapterus leucas*). Rep. prep. by Alaska Reg., Natl. Mar. Fish. Serv., 222 W. 7th Ave., #43, Anchorage, AK 99513-7577, 22 p.

[15]Shelden. K. E. W., and B. A. Mahoney. 2016. Aerial surveys of beluga whales in Cook Inlet, Alaska, June 1991. AFSC Proc. Rep. 2016-02, 22 p. Available at http://www.afsc.noaa.gov/Publications/ProcRpt/PR2016-02.pdf.

[16]Shelden, K. E. W., C. L. Sims, L. Vate Brattström, K. T. Goetz, and R. C. Hobbs. 2015. Aerial surveys of beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2014. AFSC Proc. Rep. 2015-03, 55 p. Available at http://www.afsc.noaa.gov/Publications/ProcRpt/PR2015-03.pdf and accessed 8 Sept. 2015.

[17]Hansen, D. J., and J. D. Hubbard. 1999. Distribution of Cook Inlet beluga whales (*Delphinapterus leucas*) in winter. U.S. Dep. Inter., Bur. Land. Manage., Minerals Manag. Serv., Environ. Stud. Sec., Alaska OCS Reg., OCS Study MMS 99-0024, 30 p. (avail. at http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/reports/distribution_hansen_hubbard99.pdf and accessed 16 Mar. 2015).

[18]Goetz, K. T., P. W. Robinson, R. C. Hobbs, K. L. Laidre, L. A. Huckstadt, and K. E. W. Shelden. 2012. Movement and dive behavior of beluga whales in Cook Inlet, Alaska. AFSC Proc. Rep. 2012-03, 40 p (avail. at http://www.afsc.noaa.gov/Publications/ProcRpt/PR2012-03.pdf and accessed 5 Dec. 2013).

ent as are counted in this type of survey. Using a correction factor of 2.7 to account for submerged whales (which was developed for estimating belukha whales in similar conditions in Bristol Bay) yields a minimum estimate of 1,293 whales in Cook Inlet in August 1979" (p. 110).

Applying this correction (2.75 per Frost et al. (1985)) to surveys undertaken by NMFS in June 1991 (Shelden and Mahoney[15], correcting the estimate presented in NMFS[14]), where the highest count was 370 whales on a single day, resulted in an estimate of 1,018 belugas. Subsequent estimates produced from NMFS surveys (1994–2014) were based on correction factors developed for Cook Inlet (Hobbs et al., 2015a). These estimates show a steep decline in abundance prior to the moratorium on Alaska Native subsistence hunting (1994–98: -13.7% (SE = 4.5%) per year), and a 1.3% (SE = 0.8%) per year decline since harvest management regulations were put in place in 1999 (Shelden et al.[16]). The Cook Inlet stock was listed as depleted under the U.S. Marine Mammal Protection Act in 2000 (NOAA, 2000). In 2008, the Cook Inlet population was listed as endangered under the U.S. Endangered Species Act (NOAA, 2008).

This paper provides a review of CIBW spatio-temporal distribution based on results from aerial surveys, satellite-telemetry, and opportunistic sightings. With the continued decline in abundance of CIBWs (Hobbs et al., 2015a) and concomitant contraction in range observed during early summer (Rugh et al., 2010), identifying areas used by these whales during ice-covered and ice-free periods is critical to the recovery of this endangered population.

Methods

Study Area

Cook Inlet, Alaska, (lat. 59°–61.5°N, long. 149°–154°W) is a semi-enclosed tidal estuary covering an area of roughly 20,000 km^2 with 1,350 km of shoreline (Fig. 1). The inlet extends about 370 km (200 n.mi.) southwest from Knik Arm to Cape Douglas and has marine connections with Shelikof Strait and the Gulf of Alaska, and freshwater input from many large rivers.

Osgood (1933) described the inlet as four regions: Lower, Middle, Upper, and Inland, based on the villages occupied by the Athapaskan-speaking Tanaina, a sea-hunting Alaska Native culture. The lower inlet region (which included the village of Seldovia) was described as having a mild climate and salt water. The middle inlet was less mild and salt-fresh water mixed and included the villages of Kenai and Tyonek. The upper inlet included Knik Arm (the village of Eklutna) and was described as a cold climate with waters that were a mixture of dirty, fresh, and salt. Inland villages were on the Susitna River and Iliamna River, regions described as fresh water only with cold climates. Osgood (1933) noted that belugas were found in lower, middle, and seasonally, in the upper inlet. For the purposes of this paper, we simplified the division of the inlet into upper and lower regions, separated at East Foreland and West Foreland (Fig. 1).

Tides in Cook Inlet are semi-diurnal, with two unequal high and low tides per tidal day (tidal day = 24 h 50 min). The mean diurnal tidal range varies from roughly 6 m (19 ft) at Homer to 9.5 m (30 ft) at Anchorage. These extremes in tide expose vast expanses of mudflats in the upper inlet, between the Beluga River and Little Susitna River (we refer to this region as the Susitna Delta), and in Knik Arm, Chickaloon Bay, and Turnagain Arm (Fig. 1). Beluga whales navigate these regions on the flooding and ebbing tides, following the deeper channels as the mud flats flood, allowing the whales to move closer to the shoreline and into the rivers. Whales move to the edges of the mudflats, to what appears to be mid-inlet waters, as the tide ebbs. We considered the mudflat edge to be an extension of the shoreline when describing whale distribution, and mid-inlet waters are defined as deeper than 10 m (Fig. 1).

Sea ice generally forms in October–November, reaches its maximum extent in February, then recedes and melts in March–April. By December, much of the upper inlet north of North Foreland and Point Possession is covered with ice ranging in thickness from 10 cm (new/pancake) to 30–70 cm (all as first year because there is no multi-year ice present in the inlet); and in concentrations ranging from 10% to 70–80% coverage (i.e., open (1/10) to close pack (7/10 to 8/10) (Mulherin et al.[19]). Hereafter, percent coverage is used in lieu of tenths when describing ice concentrations.

Thawing and refreezing create a dynamic ice environment. Tidal action and tidal currents often shatter sea ice in Cook Inlet to the extent that there is seldom uniform coverage. Waters are typically ice-free south of East and West Foreland until January, when ice extent and thickness increase, reaching maximums between mid-February and early March (Mulherin et al.[19]). In colder winters, ice extends south as far as Anchor Point and Augustine Island, filling Kamishak Bay to Cape Douglas on the lower west side of Cook Inlet. Despite the possibility of ice entrapment, beluga whales continued to inhabit upper inlet waters (Goetz et al.[18]). In general, beluga whales are pagophilic (i.e., "ice-loving") and uniquely adapted to survive in Arctic and subarctic waters.

The endangered CIBW population lives in close proximity to Anchorage, the largest city in Alaska, and waterways frequented by fishing fleets, container ships, air traffic, oil and gas development, and military operations. The magnitude and the accumulated anthropogenic pressures within Cook Inlet beluga habitat are of particular concern for this small, isolated population (Norman et al., 2015).

[19]Mulherin, N. D., W. B. Tucker III, O. P. Smith, and W. J. Lee. 2001. Marine ice atlas for Cook Inlet, Alaska. ERDC/CRREL Tech. Rep. 01-10, 155 p. (avail. at http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA392126 and accessed 4 Dec. 2013).

Aerial Survey Datasets

Alaska Department of Fish and Game

From November 1977 through August 1979, aerial survey observers documented the seasonal distribution of CIBWs and also recorded the presence of other marine mammals including harbor seals, *Phoca vitulina*; minke whales, *Balaenoptera acutorostrata*; sea otters, *Enhydra lutris*; and harbor porpoises, *Phocoena phocoena*. Survey altitude ranged from 91 to 152 m (300–500 ft). This extensive effort included year-round surveys of coastal and mid-inlet waters in the upper and lower inlet. Survey platforms included floatplanes and helicopters with one pilot and one observer. Sightings (including group sizes) and tracklines were hand-drawn on a simple outline of the inlet or a NOAA chart of the particular area of Cook Inlet surveyed. Sometimes these data were later transcribed to another map template showing the outline of the entire inlet. Field notes were often, but not always, included with the maps that were received by NMML.

ADFG also conducted aerial surveys from May through August 1982 and April through July 1983 in upper Cook Inlet. Similar to the beluga whale surveys conducted in the 1970's, survey altitude ranged from 91 to 152 m (300–500 ft). Survey aircraft were primarily single engine floatplanes with one pilot and one or two observers onboard. Field notes or annotated maps displayed flight paths and sightings. Unlike the MMS and NMFS surveys described in the following sections, the ADFG efforts were not documented in annual field reports or publications; therefore, Appendices 1 (1977–79) and 2 (1982–83) include transcriptions of all available field notes, survey tracklines, and sighting locations.

Maps were created using ArcView[20] geographical information system software (ver. 10.1). Plots showing sighting locations were projected using the Alaska Albers Equal Area Conic coordinate system which provided a more accurate depiction for area-use measurements. Each map was scanned and saved into a PDF, then the digital image was exported as a JPEG file. This file was imported into ArcMap as a raster dataset layer and saved as a georeferenced map. Beluga sighting locations and survey tracklines were redrawn as graphics then converted to shapefiles. The sighting shapefiles were edited to include group sizes for the maps in Appendices 1 and 2.

Minerals Management Service

In 1997, aerial surveys for beluga whales in ice-free areas of Cook Inlet occurred from 12 Feb. through 14 Mar. (Hansen and Hubbard[17]). Surveys were flown in a Twin Otter equipped with side bubble windows for the two observers. These windows allowed observers to view ahead of and beneath the aircraft. Similar to the NMFS surveys described in the following section, a computer operator collected survey data using an acquisition program designed for marine mammal surveys. The surveys covered 9,406 km of trackline and were flown at an altitude of 305 m (1,000 ft). Daily summaries and maps that included trackline effort and marine mammal species observations are provided in Appendix B in Hansen and Hubbard[17]. Beluga whale sighting locations (lat., long. from Table 4 in Hansen and Hubbard[17]) were imported and plotted in ArcMap. Group sizes and general locations of these sightings are provided in Table 1.

National Marine Fisheries Service

During the period 18–21 June 1991, aerial surveys[21] were flown to document the distribution and group sizes of beluga whales in Cook Inlet (Shelden and Mahoney[15]). The survey aircraft was a NOAA Twin Otter that was equipped with side bubble windows for the two observers. The survey altitude range was 152 to 305 m (500–1,000 ft). A computer operator collected survey data using an acquisition program designed for marine mammal surveys. Effort included coastal and mid-inlet waters north of Chinitna Bay and Anchor Point. Daily summaries and maps are provided in Shelden and Mahoney[15].

From 1993 to 2012, NMFS conducted annual surveys to determine abundance and distribution of belugas in Cook Inlet (hereafter referred to as "NMFS abundance surveys") (Rugh et al., 2000; 2005; Shelden et al., 2013) after which NMFS began a series of biennial surveys in 2014 (Hobbs, 2013; Shelden et al.[16]). Flights primarily took place in June, though in some years surveys began in late May (2005, 2011, and 2012), or were conducted in July (1993 and 1995). Surveys were flown in twin engine, high wing aircraft (Aero Commander or Twin Otter) equipped with side bubble windows. Surveys were flown at an altitude of 245 m (800 ft). Because most sightings occur near shore, two observers were positioned on the shoreward side of the aircraft, independently recording observations to help assess how often groups were missed. A third observer scanned mid-inlet waters and a computer operator recorded survey data. All marine mammals observed within the study area were included in the sighting database (Shelden et al., 2013:87–122).

Survey effort during the NMFS abundance surveys was fairly consistent across years with at least two survey flights covering lower inlet waters (south of East and West Foreland and north of Cape Douglas and Elizabeth Island) and multiple flights over the upper inlet. Daily summaries and maps showing sightings and trackline effort were published in Rugh et al. (2000, 2005) and Shelden et al. (2013). Surveys on a smaller scale were conducted in May (Rugh et al.[22]), August (Hobbs

[20]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA

[21]Until recently (February 2013), the original data from these surveys were thought lost. The only description of this survey, a short summary and single map, existed in an unpublished document titled "Status Report on Cook Inlet Belugas (*Delphinapterus leucas*)" (NMFS [text footnote 14], p. 7–9). Discovery of a floppy disk containing the original survey data led to the preparation of a field report in March 2013.

[22]Rugh, D. J., K. T. Goetz, and C. L. Sims. 2006. Aerial surveys of belugas in Cook Inlet, Alaska, May 2006. Unpubl. field rep., 8 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/

Table 1.—Beluga whale group sizes and sighting locations during February–March 1997 aerial surveys conducted by U.S. Department of Interior, Minerals Management Service (Hansen and Hubbard, text footnote 17).

	Beluga whale group sizes					
	Lower inlet				Upper inlet	
	Kalgin Island					
Date	SW tip	NW tip	NE tip	S of West Foreland	Near Boulder Pt.	Total
12 Feb.	12					12
15 Feb.						0
28 Feb.		36	1		13	50
01 Mar.		12	22			34
03 Mar.						0
12 Mar.				24		24
13 Mar.		11				11
14 Mar.		9			10	19

et al., 2015b; Rugh et al.[23, 24], Shelden et al.[25,26,27,28,29], Sims et al.[30]), September (Withrow et al.[31]; Shelden et al.[32]), and October (Shelden et al.[32]).

To document year-round beluga whale distribution, surveys were flown 1–2 days each month (with the exception of December and March) from July 2001 to April 2002 (Rugh et al., 2004). Aircraft and methods were the same as those used during the NMFS abundance surveys. Effort included coastal and mid-inlet waters in the upper inlet, and mid-inlet tracklines between East and West Foreland and the southern tip of Kalgin Island in the lower inlet. Daily summaries and maps showing sightings and effort were published in Rugh et al. (2004).

Beluga whale sighting locations from all of the NMFS surveys were imported and plotted in ArcMap. Group size estimates from the NMFS abundance surveys have been corrected for availability and perception biases (see Hobbs et al., 2015a) but counts from all other studies (ADFG, NMFS, and MMS) are uncorrected.

Overview of Aerial Methods

It is important to note the differences and similarities among these aerial surveys. Surveys conducted by ADFG in the 1970's and 1980's were at lower altitudes (300–500 ft), in single engine airplanes or helicopters, and usually with only one observer on board. Although the pilot also searched for whales, detectability would be biased downward. MMS and NMFS surveys followed similar protocols with paired observers, side bubble windows, and survey altitudes at or above 800 ft. This improves detections though whale groups may still be missed (Hobbs et al., 2015a). Coverage of the inlet varied from project to project and season to season (e.g., Appendices 1 and 2, Rugh et al., 2004), largely driven by weather and day length, such that the summer period had the greatest amount of survey effort (Fig. 3). Therefore, we present the seasonal results by year (representing each project) and month, to account for any similarities or differences in subsequent analyses and discussions.

Satellite Tagging Dataset

Beluga whales in Cook Inlet were captured and tagged in late May 1999 (n = 1), September 2000 (n = 2), late July–August 2001 (n = 7), and late July–August 2002 (n = 8) (Table 2). The tagged whales included eight males and ten females ranging in size from 257 to 442 cm. Tags were placed on the dorsal ridge and held in place via plastic pins inserted through the blubber layer below the ridge (Fig. 4). Belugas were instrumented with either a satellite-linked time-depth recorder (Wildlife Computers Ltd., Redmond, WA) containing a Telonics ST-16 ARGOS transmitter (Telonics, Mesa, AZ) (ST-16), a smart position or temperature transmitting tag (SPOT2) (Wildlife Computers Ltd., Redmond, WA), or both (Table 2). Tags were programmed to transmit 24 hours a day (ST-16) or every 10 days for 24 hours

beluga/survey/report0506.pdf and accessed 19 July 2011).

[23]Rugh, D. J., K. T. Goetz, and B. A. Mahoney. 2005. Aerial surveys of belugas in Cook Inlet, Alaska, August 2005. Unpubl. field rep., 8 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/aerialsurvey05.pdf and accessed 19 July 2011).

[24]Rugh, D. J., K. T. Goetz, C. L. Sims, and B. K. Smith. 2006. Aerial surveys of belugas in Cook Inlet, Alaska, August 2006. Unpubl. field rep., 9 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2006.pdf and accessed 19 July 2011).

[25]Shelden, K. E. W., K. T. Goetz, and J. A. Mocklin. 2007. Aerial surveys of belugas in Cook Inlet, Alaska, August 2007. Unpubl. field rep., 11 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2007.pdf and accessed 19 July 2011).

[26]Shelden K. E. W., K. T. Goetz, L. Vate Brattström, B. A. Mahoney, M. Migura-Krajzynski, and B. S. Stewart. 2008. Aerial surveys of belugas in Cook Inlet, Alaska, August 2008. Unpubl. field rep., 11 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2008.pdf and accessed 19 July 2011).

[27]Shelden K. E. W., K. T. Goetz, L. Vate Brattström, and B. A. Mahoney. 2009. Aerial surveys of belugas in Cook Inlet, Alaska, August 2009. Unpubl. field rep., 11 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/august09.pdf and accessed 19 July 2011).

[28]Shelden K. E. W., L. Vate Brattström, and C. L. Sims. 2010. Aerial surveys of belugas in Cook Inlet, Alaska, August 2010. Unpubl. field rep., 12 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/august2010.pdf and accessed 19 July 2011).

[29]Shelden K. E. W., L. Vate Brattström, and C. L. Sims. 2011. Aerial surveys of belugas in Cook Inlet, Alaska, August 2011. Unpubl. field rep., 10 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/august2011.pdf and accessed 25 Jan. 2012).

[30]Sims, C.L., L. Vate Brattström, and K. T. Goetz. 2012. Aerial surveys of belugas in Cook Inlet, Alaska, August 2012. Unpubl. field rep., 11 p. (avail. at http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/survey/august2012.pdf and accessed 14 Nov. 2013).

[31]Withrow, D. E., K. E. W. Shelden, D. J. Rugh, and R. C. Hobbs. 1994. Beluga whale, *Delphinapterus leucas*, distribution and abundance in Cook Inlet, 1993. *In* H. Braham and D. DeMaster (Editors), Marine Mammal Assessment Program: status of stocks and impacts of incidental take; 1993, p. 128–153. Annu. Rep. submitted to Off. Protected Resour., NMFS, NOAA, 1335 East-West Highway, Silver Spring, MD 20910. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/reports/withrowetal1993.pdf and accessed 19 July 2011).

[32]Shelden K. E. W., K. T. Goetz, C. Sims, and B. A. Mahoney. 2008. Aerial surveys of belugas in Cook Inlet, Alaska, September and October 2008. Unpubl. field rep,. 9 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/sept_oct08.pdf and accessed 19 July 2011).

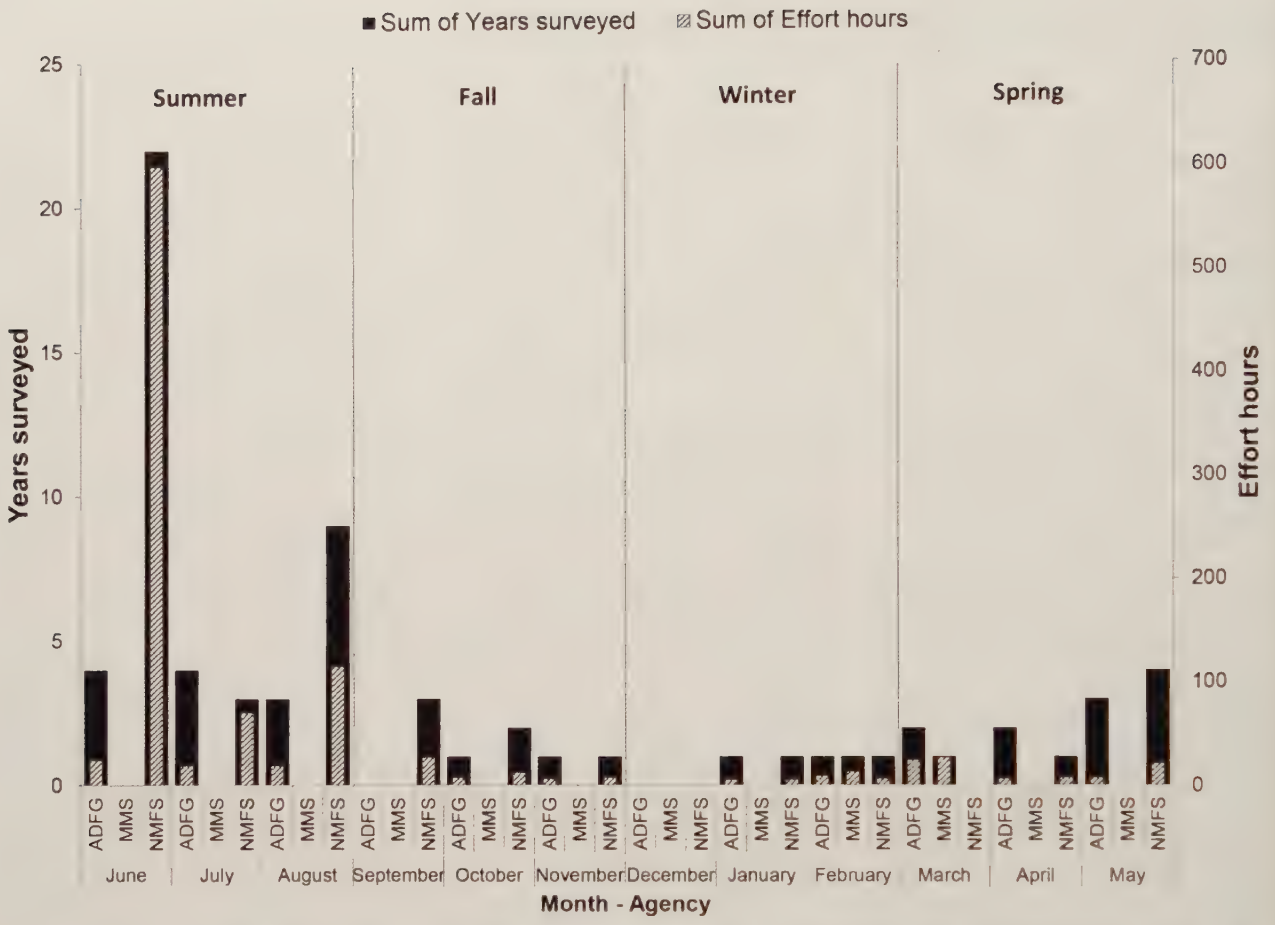


Figure 3.—Aerial surveys documenting beluga whales in Cook Inlet, Alaska, conducted by the Alaska Department of Fish and Game (ADFG:1977–79, 1982–83), Minerals Management Service (MMS: 1997), and National Marine Fisheries Service (NMFS: 1991, 1993–2012, 2014). Effort hours were compiled for all surveys, which ranged from 1 day to 11 days within each month during a particular year, and included 1–3 flights per day. ADFG effort hours were estimated for some surveys based on trackline coverage and similar surveys that included field notes when field notes were not available (Appendix 1 and 2).

(SPOT2). Tags transmitted locations from capture date to last uplink from 1 to 295 days (average = 116.4, SD = 84.5) (Table 2). Goetz et al.[18] reanalyzed tag data presented in Ferrero et al. (2000) and Hobbs et al. (2005), applying a land avoidance algorithm and removing gaps in data of longer than 1 day from the interpolated track. We used this revised dataset for the seasonal distribution analysis. Maps displaying individual whale locations each month for the four study years are provided in Appendix 3, with the exception of the four whales whose tags transmitted for fewer than 2 analysis days (Table 2).

Opportunistic Sightings Dataset

NMFS maintains a Microsoft Access database of beluga whale sightings provided by the public opportunistically (i.e., no associated effort data), from aircraft patrols (e.g., Civil Air Patrol, NMFS Enforcement, and military recon), dedicated beluga whale surveys (vessel, shore-based, and aerial), other wildlife surveys, and industry monitoring studies. The CIBW Opportunistic Database was queried for all sightings from 1975 (the earliest reported sighting in the database) through 2014. Sightings from beluga whale aerial surveys that had associated effort (ADFG, NMFS-NMML, and MMS) were excluded as these are presented in the aerial survey datasets section. Although a number of monitoring studies have occurred in Cook Inlet, particularly in the last decade (e.g., Polasek et al., 2015; Carlson et al., 2015; Kendall and Cornick, 2015), we included these data here only if sightings were provided to NMFS for inclusion in the database.

We note that after the moratorium on the subsistence hunt in 1999, and subsequent listing of the CIBW population as endangered, the number of sightings in the database increased substantially due to public outreach,

Table 2.—Tag type, date deployed and duration, tagging location, and physical characteristics of beluga whales tagged in Cook Inlet, Alaska, between 1999 and 2002. Animal ID was created for the mapping database to provide a unique identifier for PTT numbers that were used over multiple years. NA = not analyzed (< 1 day of uplinks), NT = no transmissions, L = 4 batteries, S = 2 batteries. "Days" = total days from capture date to last satellite uplink. For whales with two functioning tags (*n* = 3), transmission data were combined into one continuous time series for "days" and "analysis days" (shown in parentheses). "Analysis days" represent good quality uplinks only. Length was measured as straight length usually in feet and inches then converted to centimeters (note: some conversion errors occurred in Hobbs et al. (2005)). Photo-ID is currently in progress, therefore, only a 100% confirmed match to photographs taken during tagging are shown (T. McGuire, LGL Research Associates, Anchorage, AK). See Appendix 3[1] for maps of capture locations and monthly movements.

Beluga ID				Satellite-linked tags							Whale characteristics			Recaptured	
Field notes	Pectoral band (Left/ Right)	Hobbs/Goetz[4]	Animal ID	Type	PTT	Capture location	Capture date	First uplink	Final uplink	Days (analysis days)	Sex	Color	Length feet (cm)	Photo-ID (aft 2005)	Stranded/Died
RCF 400[2]	DL00141(L) DL00142(R)	CI-9901[5]	25850111	ST-16	25850	Little Susitna	31 May 1999	Same day	17 Sept 1999	109 (103.0)	M	White	370		
CI-DL-03-00[3]		CI-0001	25850112	ST-16	25850	Knik Arm	13 Sept 2000	14 Sept 2000	06 Jan 2001	115 (111.5)	M	White	13'7"(413)		
CI-DL-02-00[3]		CI-0002	30719114	ST-16	30719	Knik Arm	13 Sept 2000	Same day	18 Jan 2001	127 (126.3)	F	White/gray	8'11"(272)	Yes	
CI-01-01		CI-0101	13934102	SPOT2	13934	Little Susitna	10 Aug 2001	19 Sept 2001	10 Dec 2001	122 (5.6)	F	Gray	8'5"(257)	Yes	
CI-01-02		CI-0102	13937103	ST-16/ SPOT2	30720/ 13937	Knik Arm	11 Aug 2001 16 Sept 2001	NT/	NT/	107 (5.6)	M	White	10'7"(323)		
CI-01-03		CI-0103	13933101	ST-16/ SPOT2	25847/ 13945	Knik Arm	12 Aug 2001/	13 Aug 2001/ 29 Sept 2001	2 Oct 2001/ 20 Dec 2001	130 (21.8)	F	White	10'3"(312)		
CI-01-04		CI-0104[5]	NA	ST-16/ SPOT2	25849/ 13945	Knik Arm	13 Aug 2001	NT/ 30 Aug 2001	NT/ 31 Aug 2001	18 (< 1)	F	White	11'2"(340)		
CI-01-05		CI-0105	13938104	SPOT2	13938	Knik Arm	13 Aug 2001	16 Aug 2001	01 Jan 2002	141 (14.9)	F	White	11'8.5"(357)		
CI-01-06		CI-0106	13942105	ST-16/ SPOT2	13947/ 13942	Knik Arm	15 Aug 2001	16 Aug 2001/ 22 Aug 2001	28 Nov 2001/ 27 Nov 2001	105 (94.7)	F	White	13'2"(401)	Yes	
CI-01-07		CI-0107	13943106	ST-16/ SPOT2	13948/ 13943	Knik Arm	20 Aug 2001	21 Aug 2001/ 21 Sept 2001	09 Mar 2002/ 06 Jan 2002	201 (200.3)	M	White	14'6"(442)		
CI2002-01	DL00126(R)	CI-0201	25850113	ST-16 L	25850	Little Susitna	29 July 2002[6]	Same day	31 Oct 2002	94 (91.5)	M	White	13'6"(412)		
CI2002-02	DL00129(L)	CI-0202[5]	NA	ST-16 L	30719	Little Susitna	30 July 2002	31 July 2002	31 Aug. 2002	32 (< 1)	F	White/gray	11'2"(340)		
CI2002-03	DL00202(L)	CI-0203	13943107	ST-16 S	13943	Knik Arm	31 July 2002	01 Aug 2002	24 Aug 2002	24 (23.2)	F	White	12'0"(366)		
CI2002-04	DL00196(R)	CI-0204[5]	NA	ST-16 L	25849	Little Susitna	01 Aug 2002	Same day	02 Aug. 2002	1 (< 1)	F	White	12'5"(379)	No	9 Aug. 2002
CI2002-05	DL00200(L)	CI-0205	13947108	ST-16 S	13947	Knik Arm	02 Aug 2002	03 Aug 2002	01 Apr 2003	242 (215.8)	M	White/gray	12'8"(386)	Yes	12 June 2015
CI2002-06	DL00078(R)	CI-0206	13948109	ST-16 S	13948	Knik Arm	03 Aug 2002	04 Aug 2002	22 Mar 2003	231 (200.6)	M	White/gray	11'7"(353)	Yes	
CI2002-07	DL00133(R)	CI-0207	NA	ST-16 L	30720	Knik Arm	03 Aug 2002	04 Aug 2002	05 Aug 2002	2 (< 1)	F	White	12'3"(374)		
CI2002-08	DL00219(L)	CI-0208	25847110	ST-16 S	25847	Knik Arm	04 Aug 2002	05 Aug 2002	26 May 2003	295 (264.7)	M	White/gray	12'4"(376)	Yes	26 May 2014

[1] Available in the online version of this article (doi: 10.7755/MFR.77.2.1).

[2] Ferrero et al. (2000)

[3] Litzky, L. K., R. C. Hobbs, and B. A. Mahoney. 2001. Field report for tagging study of beluga whales in Cook Inlet, Alaska, September 2000, p. 13-19 *In* A. L. Lopez and R. P. Angliss (Editors), Marine Mammal Protection Act and Endangered Species Act implementation program 2000, p. 13–19. AFSC Proc. Report 2001-06, 115 p. http://www.afsc.noaa.gov/Publications/ProcRpt/PR%202001-06.pdf.

[4] The original version of Goetz et al. (text footnote 18) contained ID numbers that did not match those presented in Hobbs et al. (2005). The report was revised in January 2016 to include corrected ID numbers.

[5] Not included in Hobbs et al. (2005)

[6] Year is incorrect (2001) in Table 1 in Hobbs et al. (2005).

Figure 4.—Cook Inlet belugas were instrumented with either a satellite-linked time-depth recorder (Wildlife Computers Ltd., Redmond, WA) containing a Telonics ST-16 ARGOS transmitter (Telonics, Mesa, AZ) (ST-16), or a smart position or temperature transmitting tag (SPOT2) (Wildlife Computers Ltd., Redmond, WA), or both during the 1999–2003 tagging project.

NMFS enforcement patrols, and monitoring studies (Table 3). Most sightings in the lower inlet were opportunistic (78%), while monitoring and patrols provided almost half of the sightings reported in the upper inlet.

Data Analysis

Beluga whale sightings were identified by year (representing each aerial survey project) as well as month when plotting the seasonal distributions for summer (June–Aug.), fall (Sept.–Nov.), winter (Dec.–Feb.), and spring (Mar.–May). Each sighting record on these plots represents a sighting location, not total number of belugas seen. For the summer, when much of the aerial survey effort took place (Fig. 3), each month includes separate maps for the 1970's, 1980's, 1990's, and 2000's, to alleviate the occurrence of overlapping sightings. Tagging data were also plotted by month within each season, and identified by year. Additional data summaries include specific dates when tag transmissions coincided with aerial survey effort or opportunistic sightings (Table 4). This provided a means to "ground truth"[33] tagged whale locations as well as document when whales were missed during aerial survey efforts.

Results and Discussion

Summer

The greatest amount of survey effort was expended during the period of June–July–August (Fig. 3). In particular, aerial surveys designed to estimate abundance of CIBWs have occurred annually, primarily in June, from 1994 to 2012 (Rugh et al., 2000; 2005; Shelden et al., 2013; Hobbs et al., 2015a) and biennially beginning in 2014 (Shelden et al.[16]). Most whales were tagged in late July and early August, only one whale was tagged in late May and transmitted locations throughout the summer season (Table 2). The CIBW Opportunistic Database yielded 865 summer sightings from the period 1975–2014, with 65% reported in August (Table 3).

June

In the 1970's and 1980's, belugas were often observed near East and West Foreland or in Trading Bay (near the mouth of McArthur River) in June (Appendices 1 and 2, respectively), but from the early 1990's until 2012, whales were not seen in these regions (Fig. 5). Beluga distribution within the inlet during June contracted into the northernmost regions of the upper

[33]Observations or measurements made at or near the surface of the earth to verify an air or space-based remote sensing survey. In this case, verifying presence of tagged whale(s) through aerial observations/opportunistic sightings in the vicinity of satellite-transmitted locations.

Table 3.—Opportunistic sightings of Cook Inlet beluga whales (CIBW) provided to the National Marine Fisheries Service, 1975–2014. Number of sightings and average group sizes are shown for each month and time period (1970's, 1980's, 1990's, and 2000's) within the lower and upper inlet (separated by East Foreland and West Foreland). The season total column includes total number of sightings within summer (June–July–Aug.), fall (Sept.–Oct.–Nov.), winter (Dec.–Jan.–Feb.), and spring (Mar.–Apr.–May). Information was collected by the general public, aircraft patrols, CIBW monitoring studies, and during surveys for other wildlife. Group sizes (when provided) represented a best estimate made by the observer. Although data lack associated effort and corrections for group sizes, these sightings provide additional, though anecdotal, information about beluga whale distribution. Number of sighting and average group sizes by month, year, and specific locations within each region are available upon request from the lead author.

	Lower Cook Inlet											Upper Cook Inlet											
	Sightings					Group size (mean)						Sightings					Group size (mean)						
Month	1970-79	1980-89	1990-99	2000-08	2009-14	1970-79	1980-89	1990-99	2000-08	2009-14	Total Sightings	1970-79	1980-89	1990-99	2000-08	2009-14	1970-79	1980-89	1990-99	2000-08	2009-14	Total Sightings	Season Total
June			1	2				1	2		3	3	1	6	163	32	39	8	24	23	24	205	
July		2	1	4			219	1	1		7		1	7	56	25		na	20	42	18	89	865
Aug.	2		2	3	1	799		7	2	6	8	2	1	49	322	179	38	25	13	21	20	553	
Sept.	1		8	18	4	6		14	9	7	31		4	40	194	108		17	14	23	14	346	
Oct.	1		1	18	2	10		75	12	na	22			7	63	49			13	18	11	119	595
Nov.		2	1	4	1		3	5	10	20	8			10	36	23			17	12	6	69	
Dec.				1					2		1			1	5	9			12	9	4	15	
Jan.		1		1	2		100		na	103	4		1		10	2		3		15	7	13	44
Feb.					2					26	2				8	1				10	20	9	
Mar.		1		3	8		na		26	6	12				19	2				11	2	21	
Apr.		7	7	6	31		23	15	10	9	51	5	4	7	39	34	10	18	6	5	5	89	340
May			2	1	7			27	3	13	10	3	1	16	88	49	45	na	40	28	10	157	

inlet temporally and spatially (Rugh et al., 2010). Though the range occupied by this population had contracted northward by the late 1990's, the percentage of whales in the population occupying the Susitna Delta remained fairly constant over time, at roughly half of the population during the periods 1978–79, 1993–97, and 1998–2008 (Rugh et al., 2010).

Knik Arm was another area occupied by large numbers of beluga whales in the 1990's (Fig. 5c) and up until 2007 (Fig. 5d), after which whales were not found in this area during the NMFS abundance surveys (Fig. 5e) (Shelden et al., 2013; Hobbs et al., 2015a; Shelden et al.[16]). Since the analyses in Rugh et al. (2010) ended with the 2008 survey, we revisited the dataset and compared the proportion of whales found in the upper inlet during the period 2009–14. The contraction in range, represented by directional distribution ellipses that captured 95% of CIBW sightings, continued northward while still centering within the Susitna Delta (Fig. 6). On average, 83% (SE = 5%; $n = 320$) of the population was observed in the Susitna Delta during 2009–14, compared to half of the population during the earlier time periods (Rugh et al., 2010).

The satellite-tagged whale remained near the Little Susitna River, among the largest number of whales (average group size = 248, range 178–314) seen in the Susitna Delta during the NMFS abundance survey in June 1999 (Table 4). Only on 17 June did this whale venture across the inlet to Point Possession before looping back to Fire Island and returning to the Susitna Delta that same day (Fig. 7a).

Opportunistic sightings in the lower inlet were rarely reported in June and group sizes were typically 1–2 animals (Table 3). Almost all sightings reported in the upper inlet were north of Trading Bay (North Foreland) and Moose Point (Fig. 1). Similar to the NMFS abundance surveys, the last reports of belugas in upper Knik Arm (i.e., Eagle Bay/Goose Bay area and north) during early June were in 2007, with more recent reports occurring only near the entrance of Knik Arm at the Port of Anchorage.

July

Mid-inlet waters and much of the lower inlet coastline were not surveyed by ADFG in 1978 and 1979, respectively (Appendix 1), and upper inlet surveys in the 1980's did not include Turnagain Arm (Appendix 2) (Fig. 8a, b). NMFS surveys (Rugh et al. 2000, 2004; Withrow et al.[31]) included all coastal and some mid-inlet waters in the upper inlet and south to Kalgin Island (Fig. 8c). The only year NMFS calculated an abundance estimate in July was in 1995, which also included all coastal waters north of Elizabeth Island and Cape Douglas (Rugh et al. 2000). Rugh et al. (2000) noted:

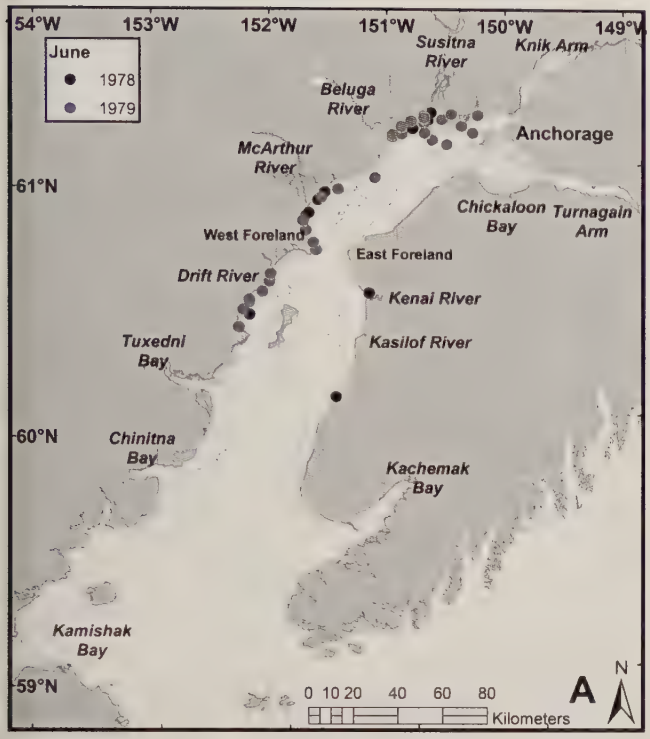
> "In the past, belugas were more concentrated in the upper inlet in June than in July: in the 1970's, the percent of sighting in the upper inlet relative to the lower inlet dropped from 86% in June to 52% in July…; and in the 1980's, percentages dropped from 100% in June to 32% in July…; but in the 1990's, this annual shift in distribution was no longer evident (from 99% to 98% for both June and July)" (p. 13).

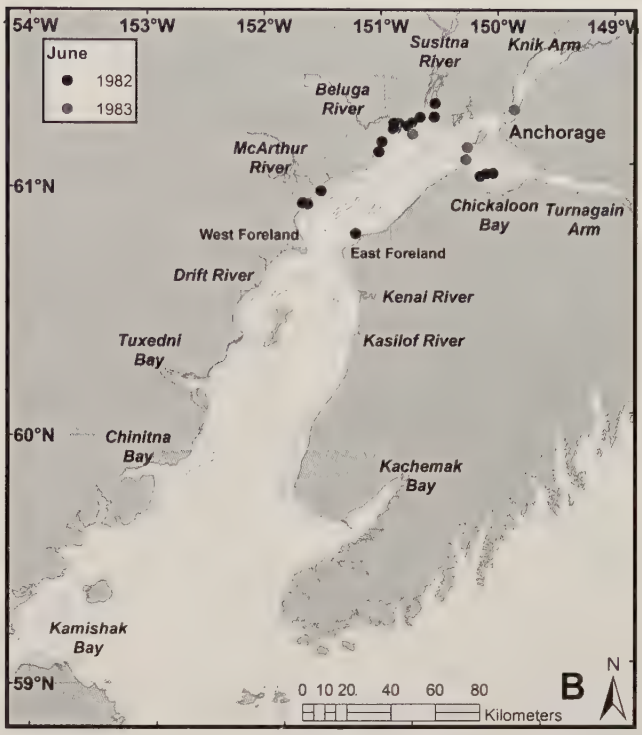
We speculate that this change in behavior (i.e., whales remaining in the upper inlet in July) continued into the 2000's. Whales were not found south of East and West Foreland in July 2001 during NMFS surveys (Fig. 8c)

Table 4.—Beluga whale tag locations in Cook Inlet, Alaska, that coincided with aerial survey effort and/or opportunistic sightings, 1999–2003.

Date or period	Description
1999 May 31	An opportunistic sighting of 30 belugas in the Little Susitna River coincided with tag transmissions.
1999 June 6, 8–14	An opportunistic sighting of 36 belugas in the Little Susitna River coincided with tag transmissions on 6 June. The tagged whale remained near the Little Susitna River during the NMFS abundance survey (8–14 June), presumably among the 178 to 314 whales estimated at that location over the course of the survey.
1999 Aug.	Six of the 23 CIBW opportunistic sightings in 1999, all in Knik Arm, coincided with tag locations. Groups ranged in size from 5 to 18 whales and were described as mixed groups of adults and juveniles.
2001 Aug. 27	Three of four whales also transmitted locations on 27 Aug., the day of the NMFS aerial survey. Aerial observers identified a lone whale with a satellite tag (CI-0106) in mid-inlet waters, and counted groups near the Little Susitna River (16 whales) and in Knik Arm (71 whales) (areas visited by CI-0107), but they did not see beluga(s) (CI-0105) near the McArthur River (Appendix 3[1]).
2001 Aug.	All CIBW opportunistic sightings during Aug. 2001 were in the upper inlet. Tag locations coincided with 11 of the 19 opportunistic sightings, all in Knik Arm. Ground truthing was difficult as multiple groups were seen some days. For example, one whale (CI-0103) transmitted locations in the vicinity of opportunistic sightings on 13 Aug. (one group of 10 whales), 24 Aug. (three groups with 10, 20, and 60 whales), and 25 Aug. (three groups with 6, 30, and 60 whales). One whale (CI-0106) was present when groups of 10 and 20 whales were observed on 20 Aug. This whale was also in the area with another tagged whale (CI-0107) when groups of 15 and 20 whales were reported on 21 Aug.
2002 Aug.	All CIBW opportunistic sightings in Aug. 2002 were in the upper inlet. Only one tagged whale's locations (CI-0203) did not coincide with any of these opportunistic sightings. Other whales' tag locations overlapped with sightings in Knik Arm (at least nine sightings) and included one to four of the remaining tagged whales among large groups of 40 to 200 whales. Near the end of the month, one whale (CI-0206) travelled from Knik Arm to Turnagain Arm where ~100 whales were reported, while another (CI-0205) went to the Little Susitna River and was presumably among the 40 whales seen that day.
1999 Sept.	Of the 29 CIBW opportunistic sightings in Sept. 1999, most in the upper inlet, tagged whale locations coincided with all sightings in Knik Arm (n = 19), but nowhere else. Group sizes during these observations ranged from 1 to 25 whales or were described as "two large groups."
2000 Sept.	Of the 27 CIBW opportunistic sightings reported during Sept. 2000, most occurred in Turnagain Arm (n = 13) and Knik Arm (n = 10). Tag locations coincided with six observations. The female beluga (CI-0002) was in Knik Arm in the vicinity of 4–5 belugas on 13 and 14 Sept., and 6–8 belugas on 17 and 18 Sept. The male beluga (CI-0001) was also near the 14 Sept. sighting. From 17 to 25 Sept., tag locations of the male beluga (CI-0001) overlapped with opportunistic reports in Turnagain Arm on 18 and 24 Sept., where group sizes, when provided, ranged from 4 to 22 whales.
2001 Sept. 15, 18	During the period when aerial surveys occurred (on 15 and 18 Sept.), four of the tags transmitted locations. Three of the tags overlapped with the aerial sightings in Knik Arm and Turnagain Arm, while the fourth whale was in Chinitna Bay.
2001 Sept.	Four CIBW opportunistic sightings were reported during Sept. 2001. Only one tag overlapped spatially and temporally with sightings, while the rest of the whales were either in others areas within the upper inlet (n = 3) or did not transmit locations on those days (n = 2, including the whale in Chinitna Bay). The adult female beluga (CI-0106) was near Point Possession on 8 Sept. (~50 whales seen) and in Turnagain Arm on 17 and 19 Sept. (~20 whales reported each day).
2002 Sept.	Tagged whales were in the vicinity of all but one of the 17 CIBW opportunistic sightings reported in the upper inlet during Sept. 2002. Half of the sightings included more than one tagged whale but never all four, though the sighting reports did not mention tagged whales. Group sizes averaged about 26 whales (range: 2–50) with the exception of one large group reported on 28 Sept. ("feeding...and stretched out covering ¾ of a mile at Beluga River" that included three tagged whales.
2000 Oct.	A CIBW opportunistic sighting in Turnagain Arm was the only one to coincide with tag locations from the male beluga (CI-0001) that had spent most of the month in Chickaloon Bay (Appendix 3). The tagged female beluga (CI-0002) was in the Susitna delta that day after having spent time in Redoubt Bay and Trading Bay earlier in the month (Appendix 3).
2001 Oct.	Five CIBW opportunistic sightings occurred during Oct. 2001, all in the upper inlet (Table 3). Sightings rarely coincided with tag locations, in part this was because some tags were duty cycled (i.e., did not transmit every day). For example, during the Trading Bay sighting on 1 Oct., when belugas were seen driving salmon toward the beach, half of the tagged whales (n = 3) were not transmitting while the rest were in Knik Arm (Appendix 3). Knik Arm CIBW opportunistic sightings on 12 and 15 Oct. included 120 whales and 15 whales, respectively. Three tagged whales, possibly as many as five (two tags transmitted in Knik Arm prior to and after this period), were in Knik Arm from 12 to 15 Oct. (Appendix 3).
2001 Oct. 12, 15	During the days when aerial surveys were flown (on 12 and 15 Oct.), three tagged whales, possibly as many as five (two tags transmitted in Knik Arm prior to and after this period), were in Knik Arm where most aerial observations occurred. NMFS aerial observers did not find whales in Chickaloon Bay though tag locations show one whale (CI-0106) occupied the area from 12 to 15 Oct.
2000 Nov.	In Nov. 2000, CIBW opportunistic sightings in the upper inlet occurred in Knik Arm, overlapping with tag locations from the female beluga (CI-0002) on every sighting, and the male whale (CI-0001) on four of the six sightings. Group sizes during these encounters ranged from 6 to 35 whales.
2001 Nov. 5	Only one CIBW opportunistic sighting was reported in the upper inlet: 65 whales in Turnagain Arm on 5 Nov. One tagged whale (CI-0106) was present but the remaining tags (n = 4) did not transmit locations that day.
2001 Nov. 9	In Nov. 2001, four tagged whales transmitted locations during the NMFS aerial survey, two from Turnagain Arm and two from Knik Arm, overlapping with the aerial observations.
2001 Dec. 17	Three whales, that appeared to be feeding as they rolled among ice floes mid-inlet off Trading Bay, were opportunistically observed by a pilot enroute to Nikiski in the vicinity of two tagged whales (Appendix 3: CI-0105 and CI-0107) that transmitted locations that day.
2002 Jan. 18–25	An opportunistic sighting in Turnagain Arm did not overlap temporally with locations from the last tag still transmitting that year, though the whale (CI-0107) had been in the vicinity the day before (Appendix 3). The opportunistic sighting report did note the absence of tags on the four whales that were milling in calm, ice-free waters. This tagged whale was likely among beluga whales observed during aerial surveys on 22 Jan. Though whales were not seen by the aerial team on 23 Jan., tag transmissions show this adult male beluga was still in the upper inlet near Trading Bay (Appendix 3), an area surveyed by NMFS that day. On 25 Jan., 30 beluga whales were seen by workers on the Grayling Oil platform in Trading Bay, an area where tag transmissions also occurred that day. The whales were in an open patch of water within the ice, swimming north on the incoming tide.
2002 Feb. 25–26	Aerial survey observers did not see whales during the two-day survey despite excellent to fair viewing conditions. Sea ice covered much of the survey area (Rugh et al., 2004). Tag transmissions from one whale (CI-0107) overlapped spatially with areas surveyed by the aerial team in the lower inlet, mid-inlet between East Foreland and Kasilof River, but we could not determine if the whale was in those locations at the same time as the aircraft.
2003 Feb. 12	An opportunistic sighting of ~15 whales swimming in circles near Fire Island occurred the same day two tagged whales were in the same area (CI-0205 and CI-0206).

[1]Appendix 3 is available in the online version of this article (doi: 10.7755/MFR.77.2.1).





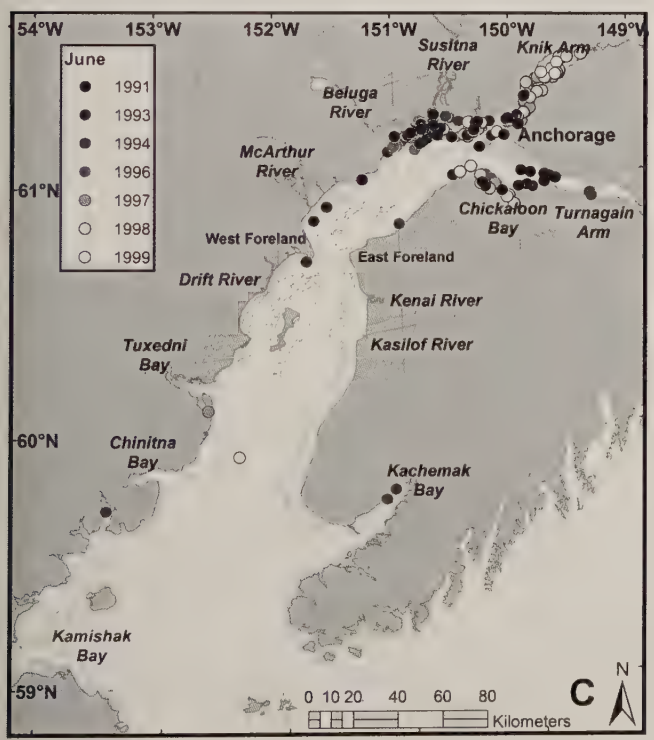


Figure 5.—Beluga whale group sighting locations during systematic aerial surveys of Cook Inlet, Alaska, in summer (June). Surveys were conducted by the Alaska Department of Fish and Game A. 1978–79, B. 1982–83, and National Marine Fisheries Service C. 1991–99, D. 2000–08, and E. 2009–14. Tidal mudflats (shaded areas) and the 10 m isobath are shown. Maps D and E are on next page.

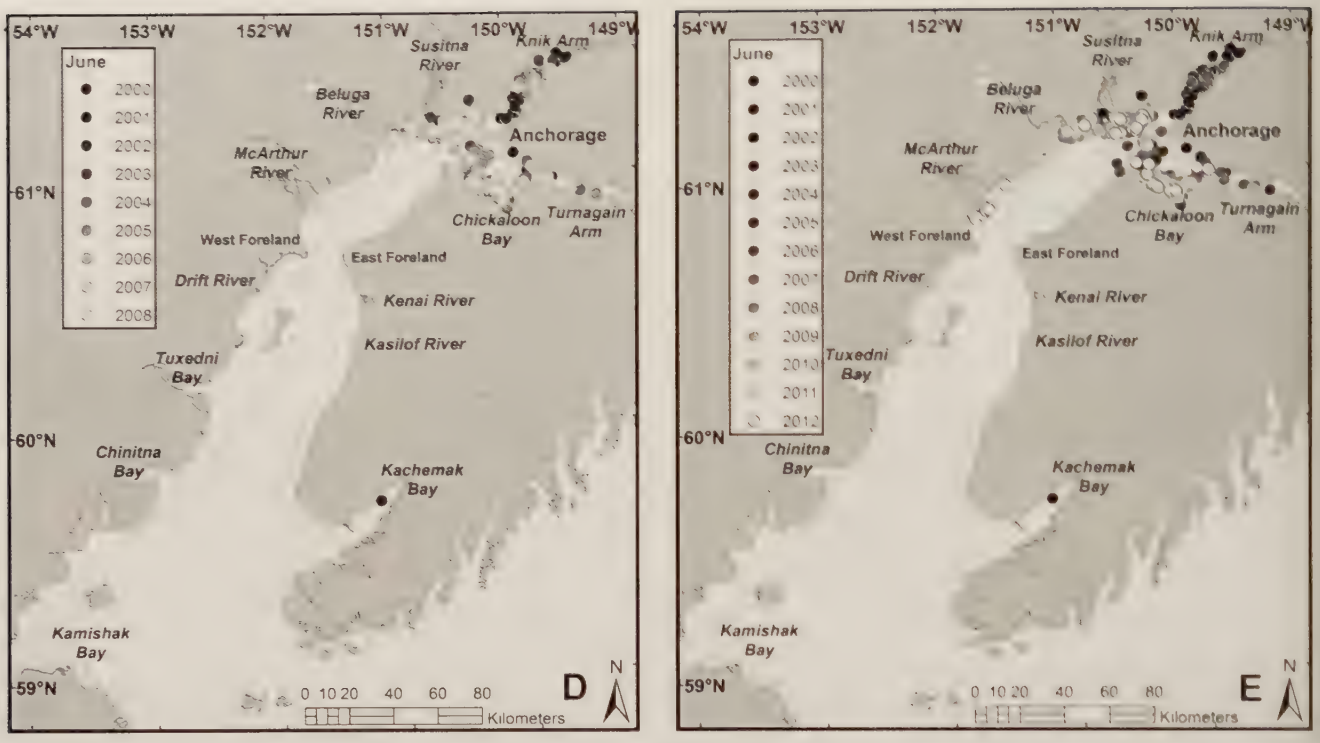


Figure 5.—*Continued*

but effort was hampered by low clouds and fog in Redoubt Bay (Rugh et al., 2004). The number of whales counted in July 2001 fell within the range of counts obtained that June (Rugh et al., 2004:6).

Whales tagged with satellite transmitters in 1999 and 2002 spent most of their time in the Susitna Delta in July (Fig. 7b). CIBW opportunistic sightings during these years did not overlap temporally or spatially with tag locations. Overall, survey efforts and sightings, both systematic and opportunistic, were less frequent in July (Fig. 3, Table 3) compared to the other summer months. Opportunistic sightings in the lower inlet included a few large groups during the 1980's. Since then, most sightings in the lower inlet have been of single whales (Table 3).

August

Aerial survey effort increased again in August with almost half of the 25 survey years sampled (Fig. 3). In the 1970's, ADFG observed large numbers of beluga whales in the inlet south of East and West Foreland in August (Appendix 1). In 1978, all beluga sightings were in the lower inlet compared to over 70% in 1979 (Fig. 9a). A similar pattern of large numbers of whales moving from upper inlet waters to the lower inlet seems evident in the 1980's. Though survey effort did not include lower inlet waters (Fig. 8b, Appendix 2), the number of whales found in the upper inlet in August 1982 (176 whales) was similar to the August 1979 count (130 whales); and when compared to early June counts in 1982 (over 300 whales, Appendix 2), there were half as many whales in the upper inlet in August.

NMFS did not conduct surveys in August in the 1990's, though by early September 1993 the whales ranged from the Drift River and Kenai River in the lower inlet (the southern extent of the survey area) to Knik Arm (see Fall section). The August 2001 NMFS survey included coastal and mid-inlet tracklines in the upper and lower inlet, south to Kalgin Island (Rugh et al., 2004). As mentioned previously, although this was not a NMFS abundance survey, the same methods were used. Whale numbers compared well with those observed in June (June, 211 belugas; August, 205 belugas) suggesting that most if not all of the population remained in the upper inlet (Fig. 9c), unlike the shifts in distribution to the lower inlet observed during the earlier time periods.

In 2005, NMFS began a series of surveys in the upper inlet to document beluga calving rates (Hobbs et al., 2015b). These surveys occurred annually until August 2012. Similar to ADFG surveys in the 1980's, all survey effort and sightings were north of East and West Foreland (Fig. 9c). Counts were similar to those obtained during the June abundance surveys for the period 2005–12 (Hobbs et al., 2015b), suggesting the contraction in range observed since the late 1970's and early 1980's occurred not only in June (as per Rugh et al., 2010) and

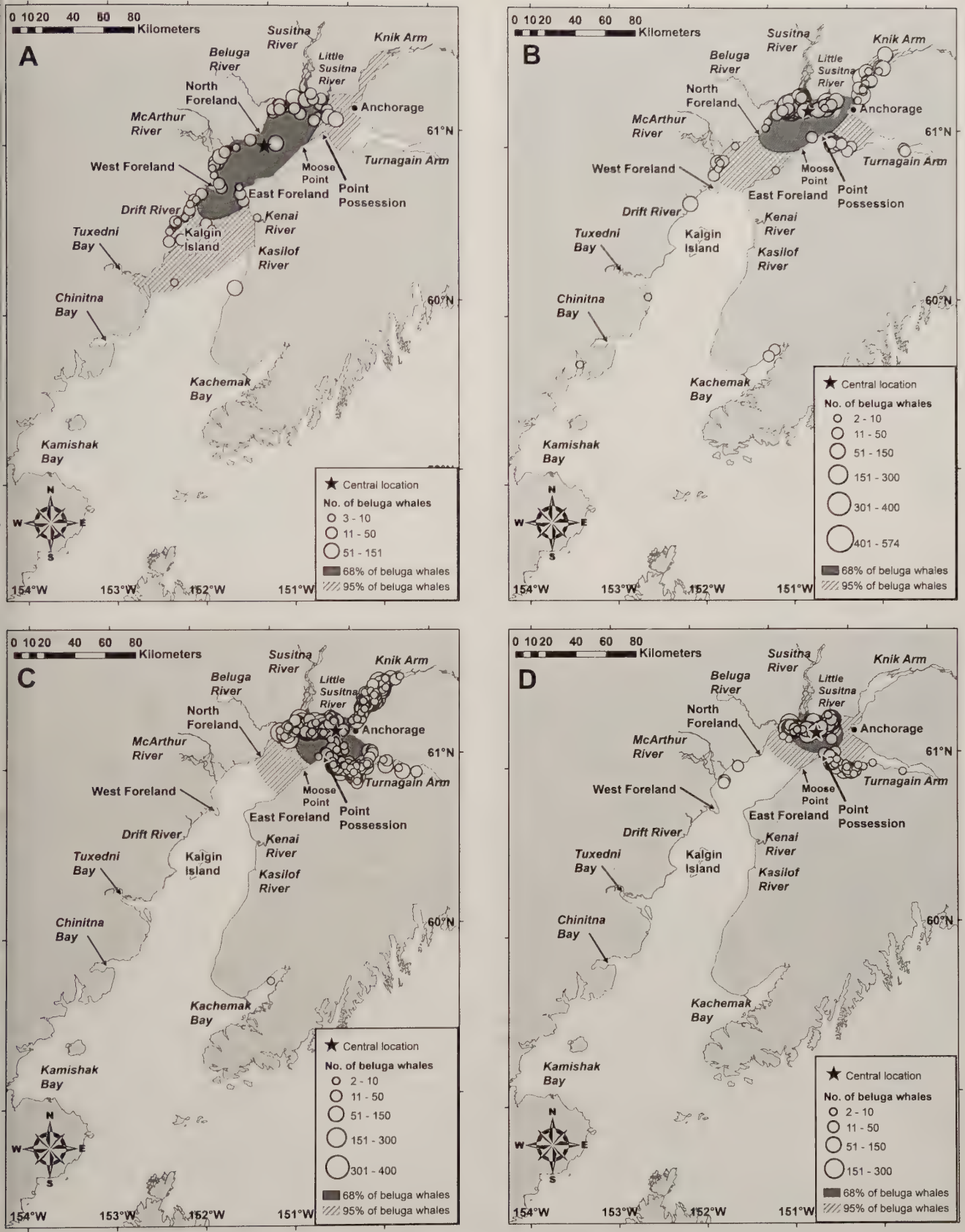
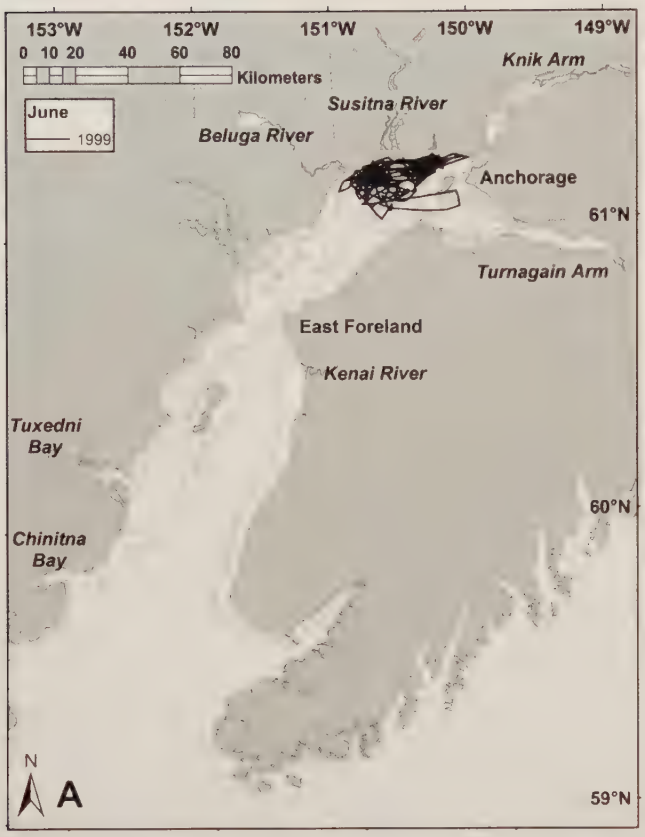


Figure 6.—Areas occupied by beluga whales in Cook Inlet, Alaska, during systematic aerial surveys in A. 1978–79, B. 1993–97, C. 1998–2008, and D. 2009–14. The distribution of beluga whales around each central location for each period was calculated at 1 and 2 SD (capturing ca. 68% and 95% of the whales; shaded regions). 95% core summer distribution contracted from 7,226 sq. km in 1978–79 to 1,787 sq. km in 2009–14 (25% of the 1978–79 range) (see Rugh et al., 2010 for methods).



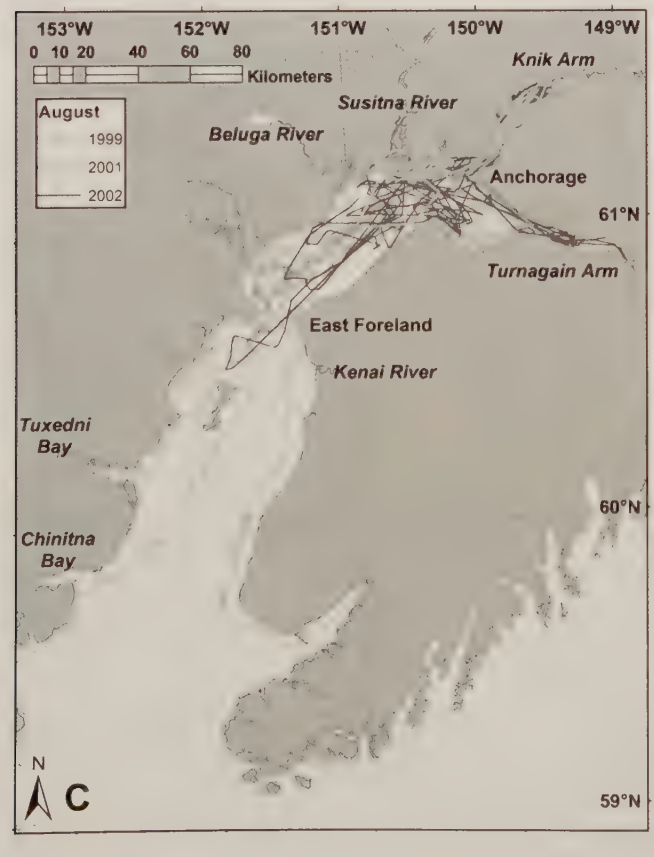
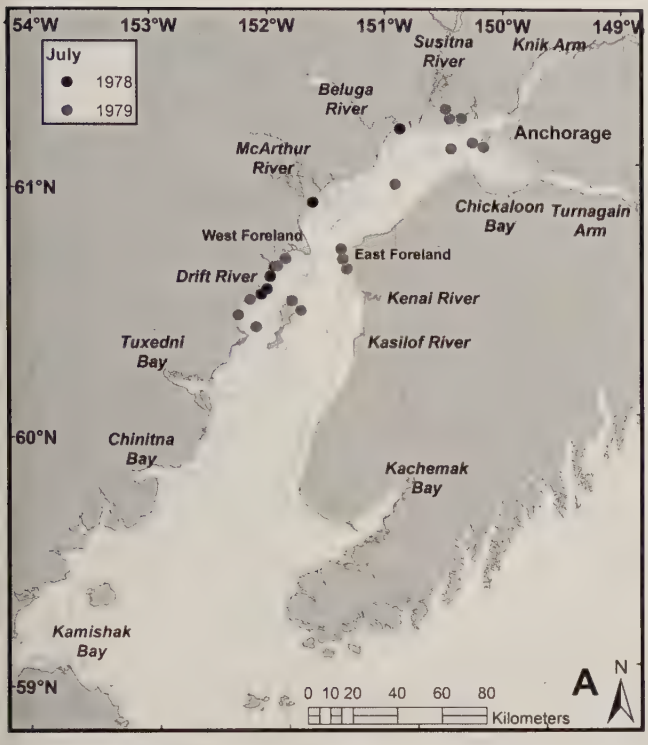
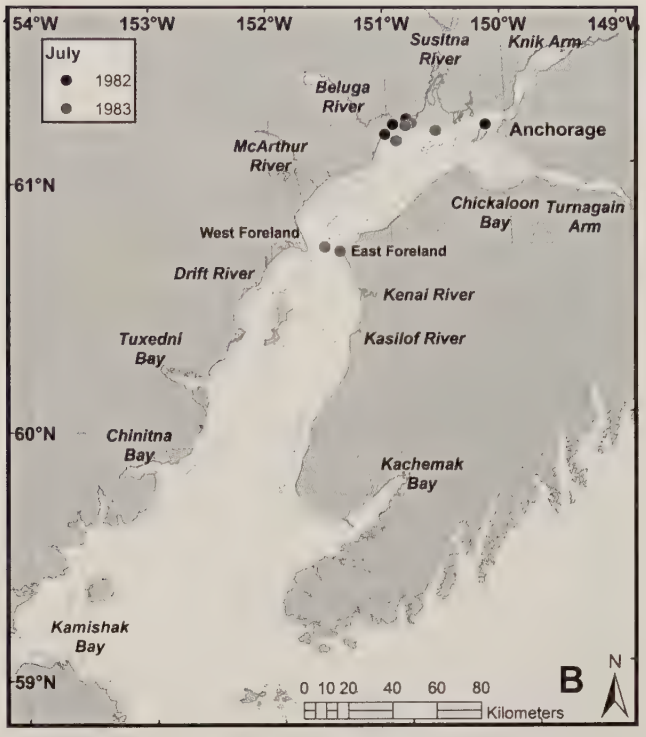


Figure 7.—Summer distribution of beluga whale satellite tag locations in Cook Inlet, Alaska, during: A. June 1999 (n = 1); B. July 1999 (n = 1) and 2002 (n = 1); and C. August 1999 (n = 1), 2001 (n = 4), and 2002 (n = 5). Tagged whales spent most of June and July in the Susitna Delta. See Appendix 3 for individual whale locations. Tidal mudflats (shaded areas) and the 10 m isobath are shown.





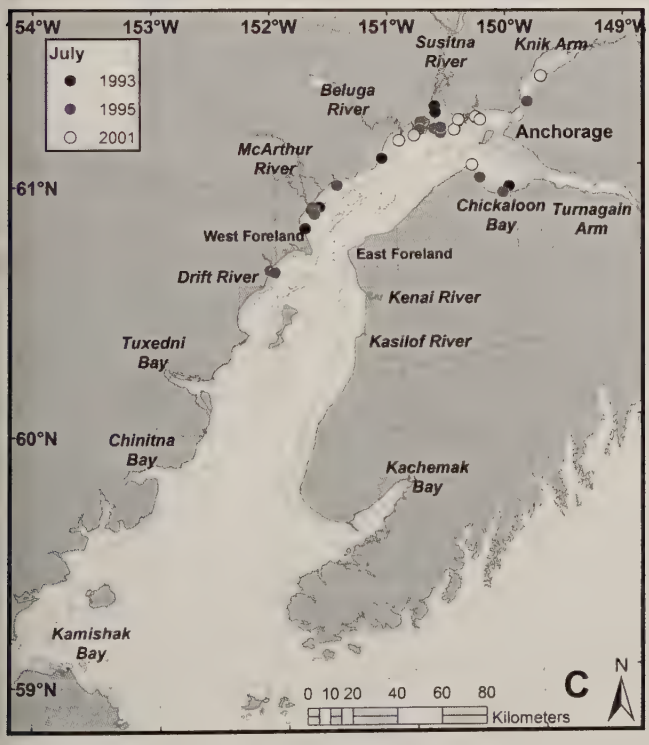


Figure 8.—Beluga whale group sighting locations during systematic aerial surveys of Cook Inlet, Alaska, in summer (July). Surveys were conducted by the Alaska Department of Fish and Game A. 1978–79, B. 1982–83, and C. National Marine Fisheries Service (1993, 1995, 2001). Tidal mudflats (shaded areas) and the 10 m isobath are shown.

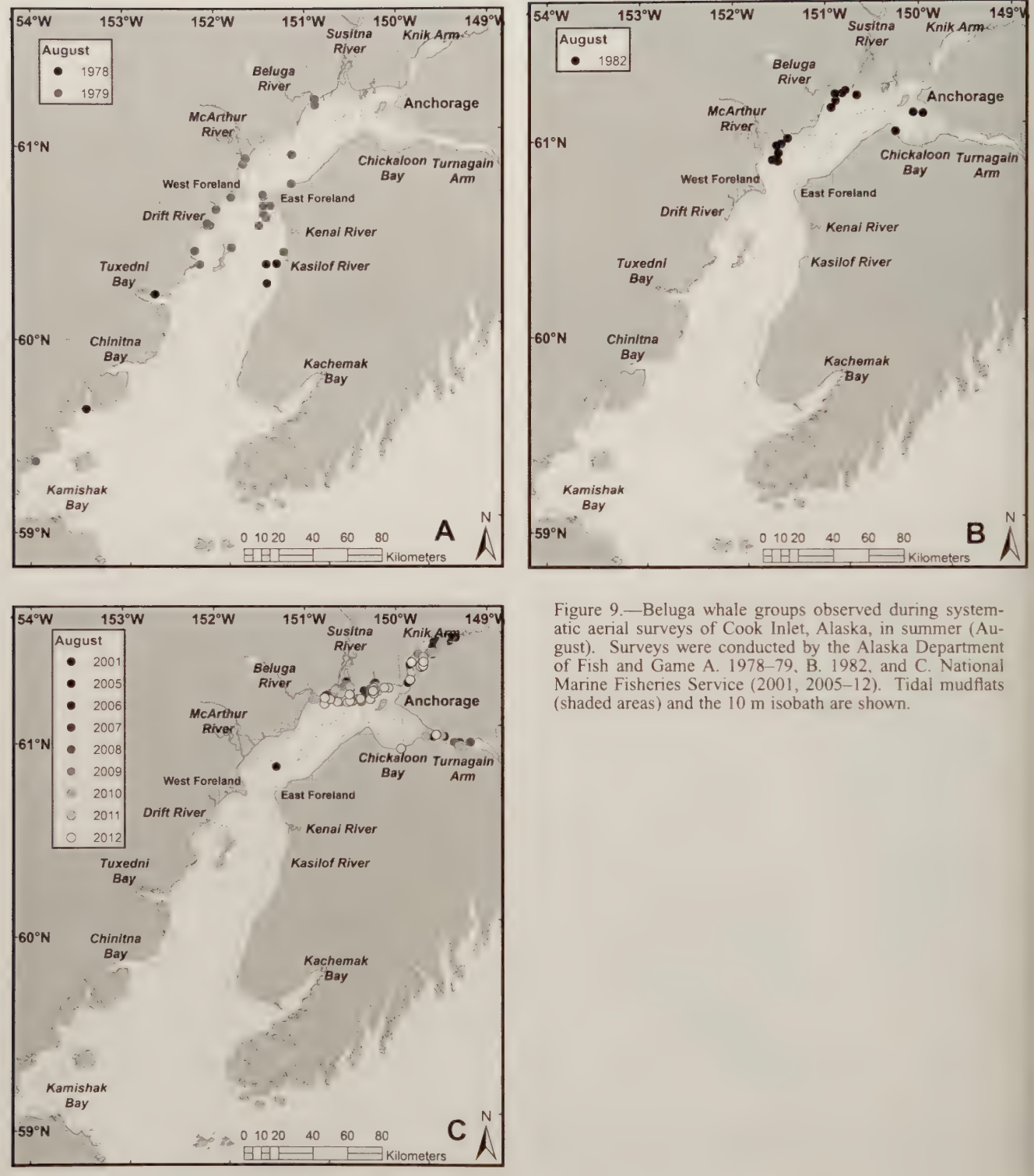


Figure 9.—Beluga whale groups observed during systematic aerial surveys of Cook Inlet, Alaska, in summer (August). Surveys were conducted by the Alaska Department of Fish and Game A. 1978–79, B. 1982, and C. National Marine Fisheries Service (2001, 2005–12). Tidal mudflats (shaded areas) and the 10 m isobath are shown.

July (Rugh et al., 2000) but also in August. Unlike the June surveys during the period 2008–12, whales were found in Knik Arm each August, often in large groups (average group size = 82, SD = 54) (Hobbs et al., 2015b).

Of the ten whales transmitting tag locations during August, only two ventured briefly south of East and West Foreland (Fig. 6c, Appendix 3). The whale tagged in 1999 remained in the upper inlet in August, primarily in Knik Arm and the Susitna Delta (Appendix 3). In 2001, most of the whales remained in the upper inlet, with the exception of one adult female who explored the waters south of West Foreland on 31 Aug. before returning to the upper inlet (Appendix 3).

In 2002, all whales transmitted locations during the month of August (Appendix 3). Similar to whales tagged in 2001, most remained in the upper inlet moving between the Susitna Delta, Knik Arm, and Turnagain Arm (Fig. 7c). One whale, the only adult female transmitting locations throughout the month, entered the lower inlet on 11 Aug. where she remained north of Kalgin Island for a day before returning to the upper inlet (Appendix 3). Tag transmissions overlapped with a number of opportunistic sightings in 1999, 2001, and 2002, and aerial survey effort in 2001 (Table 4).

Similar to July, opportunistic sightings in the lower inlet during August in the late 1970's included large groups of whales (Table 3). Since then reports of a single whale or small groups (3–13 whales) have been the norm.

Summer Discussion

Early summer had the greatest concentrations of whales in the upper inlet during all time periods. Shifts in distribution were evident in the 1970's and 1980's with large numbers of whales dispersing into lower inlet waters by mid- to late summer. This was not the case during the later survey periods when most of the Cook Inlet population continued to occupy the upper inlet well into late summer. The reduction of this population by half in the 1990's (Hobbs et al., 2015a) and the northward contraction of range during this period (Rugh et al., 2010) suggest a consolidation of the population into a few preferred habitats.

Nearly half of the population occupied the Susitna Delta in early summer during all time periods (Rugh et al., 2010), and over 83% after 2007 when whales were no longer observed in Knik Arm. Whales returned to the Susitna Delta each year, and often remained in spite of extensive Native subsistence hunting in this region during the early 1990's (Mahoney and Shelden, 2000). Goetz et al. (2012) modeled habitat preferences using the NMFS 1994–2008 abundance survey data. They found that in large areas, such as the Susitna Delta and Knik Arm, there was a high probability of beluga presence, and when present, group sizes were likely to be larger. Presence also increased closer to rivers with Chinook salmon, *Oncorhynchus tshawytscha*, runs (such as the Susitna River), and the Susitna Delta also supports two major spawning migrations of eulachon, *Thaleichthys pacificus*, a small, schooling smelt, in May and July. Stomachs from stranded belugas collected at the same time as the NMFS abundance surveys contained only Pacific salmon (Quakenbush et al., 2015).

It is not clear why belugas have not been seen in Knik Arm in June from 2008 to 2014. This change in distribution is not evident in the analyses presented by Rugh et al. (2010) or Goetz et al. (2012) because analyses ended with the June 2008 survey. Knik Arm was not abandoned for the entire summer, however, as large groups were observed here every August during the period 2008–12 (Hobbs et al., 2015b). Goetz et al. (2012) noted that anthropogenic disturbance, characterized as distance relative to coastal cities and oil development, was a significant predictor of beluga presence. Though presence increased with distance from these areas, the authors cautioned that many of the anthropogenic sources were south of the Susitna Delta, and that prey preferences rather than avoidance of development may be a stronger driver for this predicted distribution.

Belugas appear to have stronger site fidelity during the early summer period, as evidenced by a single tagged whale and aerial survey records. The one whale tagged during the beginning of this season transmitted locations throughout the entire summer period, remaining in the Susitna Delta from late May to late July, before exploring Turnagain Arm in late July, and Knik Arm in August. While some of the whales tagged in late July and August moved throughout the upper inlet in August, others remained for long periods in a few locations such as Knik Arm, the Susitna Delta, and Turnagain Arm (Appendix 3).

Preliminary analyses of the dive data collected by the tags indicate whales made shorter, shallower dives during the period from June to November compared to the longer, deeper dives recorded during December to May (Goetz et al.[18]). Closer examination of the whale tagged in late May 1999 showed time at surface increased daily over a 2-week period from 31 May to 11 June (Hobbs et al., 2015a). This would be expected as belugas follow anadromous fish runs into shallow channels within the tidal flats of the Susitna Delta. Spending more time at the surface also increases the likelihood of aerial observers detecting these whales.

Near the end of August, two of the tagged whales spent brief periods in the lower inlet. In all three years, a few whales spent time in mid-inlet waters of the upper inlet in August (Fig. 7c). These behaviors may be representative of much larger groups of whales. Unfortunately, lower inlet and most mid-inlet tag locations did not coincide with aerial survey effort or opportunistic sightings. Nevertheless, by late summer some beluga whales begin to traverse into the lower inlet and mid-inlet waters of the upper inlet.

Fall

In the fall, day length shortens and anadromous fish runs come to an end. Survey effort was also much reduced

during the September–October–November period (Fig. 3, Fig. 10). The CIBW Opportunistic Database included 595 fall sightings during the period 1975–2014 (Table 3). Most opportunistic sightings were reported in September (63%) and decreased throughout the season. Thirteen tags transmitted locations of whales during the month of September, and eleven continued to transmit into November (Fig. 11).

September

ADFG did not survey Cook Inlet in September during the 1970's and 1980's (Fig. 3). NMFS surveys in 1993 (Withrow et al.[31]) included the coastline and mid-inlet waters of Cook Inlet north of the Drift and Kenai rivers. Belugas were encountered at the northern and southern limits of this survey—ranging from Turnagain Arm and Knik Arm to Kenai River and Drift River (Fig. 10a). The highest count, 197 whales on 3 Sept., included groups ranging in size from 5 to 59 whales (Withrow et al.[31]). Whale numbers dropped substantially during the 18–19 Sept. surveys (12 and 57 whales, respectively) when whales were found only in Knik Arm, Chickaloon Bay, and Turnagain Arm.

In 2001, NMFS conducted an aerial survey that included coastal and mid-inlet waters north of Harriet Point and Kasilof River (Rugh et al., 2004). On 15 Sept., a few belugas were seen near Beluga River (3 whales) and large groups were found in Knik Arm (113 whales) and Turnagain Arm (70 whales) (Fig. 10a). This count (186 whales) was in the middle of the range of daily counts (165–210 whales, average = 186) made in June that same year (Rugh et al., 2005).

A two day survey was conducted by NMFS in September 2008 with the objective of searching for beluga whales in lower Cook Inlet. Effort included 1) a coastal trackline down the western side of the inlet from the Little Susitna River to Cape Douglas, mid-inlet tracklines, and a coastal trackline along Kachemak Bay on 19 Sept.; and 2) a coastal trackline of the upper inlet north of Point Possession and the Beluga River tidal flats on 20 Sept. (Shelden et al.[32]). All whales observed (~66 total) were in the upper inlet in Knik Arm, Turnagain Arm, and Chickaloon Bay (Fig. 10a). This count also fell within the range of counts (58–126 whales) obtained in June 2008 (Shelden et al., 2013).

With the exception of one whale that spent time in the lower inlet in Chinitna Bay, tagged whales (n = 12) remained in the upper inlet during September (Fig. 11a, Appendix 3). Whales transmitting locations in 1999 and 2000 remained in the upper inlet north of North Foreland and Point Possession (Fig. 11a). One of the whales tagged in 2000 remained in Knik Arm during September. The other left Knik Arm on 15 Sept. and travelled to Turnagain Arm and Chickaloon Bay, similar to the whale tagged in 1999 (Appendix 3).

All of the whales tagged in 2001 transmitted locations in September (Appendix 3). Most (5 of 6) remained in the upper inlet while one female whale spent at least part of the month[34] in the lower inlet in Chinitna Bay (Fig. 11a). By September 2002, four of the six tagged whales, all males, were still transmitting locations (Fig. 11a). All remained in the upper inlet, but each would at times travel independent of the other tagged whales (to Turnagain Arm or Trading Bay) then rejoin one or more in the Susitna Delta or Knik Arm (Appendix 3). Tag transmissions overlapped with a number of opportunistic sightings in 1999, 2001, and 2002, and aerial survey effort in 2001 (Table 4).

CIBW opportunistic sightings began to increase in the lower inlet during September, though most reports were still occurring in the upper inlet (Table 3). With the exception of one sighting (6 whales) in 1975 in Kachemak Bay, all reports were from 1999 to 2011 and occurred in and near the Kasilof and Kenai rivers (32%), and Chinitna (23%), Illiamna/ Iniskin/ Cottonwood (19%), Kamishak (7%), and Kachemak bays (16%).

October

In 1978, all beluga groups (75 whales total, Appendix 1) observed during aerial surveys were in the lower inlet (Fig. 10b). In 2001, NMFS flew mid-inlet transects on 12 Oct. in the upper inlet and in the lower inlet as far south as Harriet Point and Kasilof River; and on 15 Oct., a coastal survey of the upper inlet (Rugh et al., 2004). A small group of three whales was seen near the Little Susitna River during mid-inlet transects but most whales (162 total) were observed in Knik Arm during the coastline survey. Rugh et al. (2004) noted that similar to the September 2001 count, the October count of 162 whales was "well within the range of the daily counts in June...which meant that in October most of the whales were still in upper Cook Inlet" (p. 8).

On 22 Oct. 2008, NMFS flew an exploratory effort to look for belugas in Kamishak Bay similar to surveys in September of that same year (Shelden et al.[32]). The shoreline survey from Cape Douglas to the Little Susitna River included effort in some parts of Kamishak Bay and from Chinitna Bay to Point MacKenzie. Unlike the ADFG surveys in the 1970's, no whales were found.

Only 2 of the 12 tagged whales travelled into the lower inlet during October (Fig. 11b). Both followed the western shoreline south to Redoubt Bay (in 2000 and 2002) but only the whale tagged in 2002 continued south to Chinitna Bay (Appendix 3). This whale travelled 6 days from West Foreland to Chinitna Bay, exploring Tuxedni Bay and Redoubt Bay twice before returning to the upper inlet 19 days later, and remained in Trading Bay until the end of the month (Appendix 3). Tag transmissions overlapped with opportunistic sightings in 2000 and 2001, and aerial survey effort in 2001 (Table 4). No CIBW opportunistic sightings were reported during October 2002.

[34]The tag was duty cycled and transmitted locations from 1 to 16 September. When it resumed transmitting on 11 October, the whale had returned to Knik Arm.

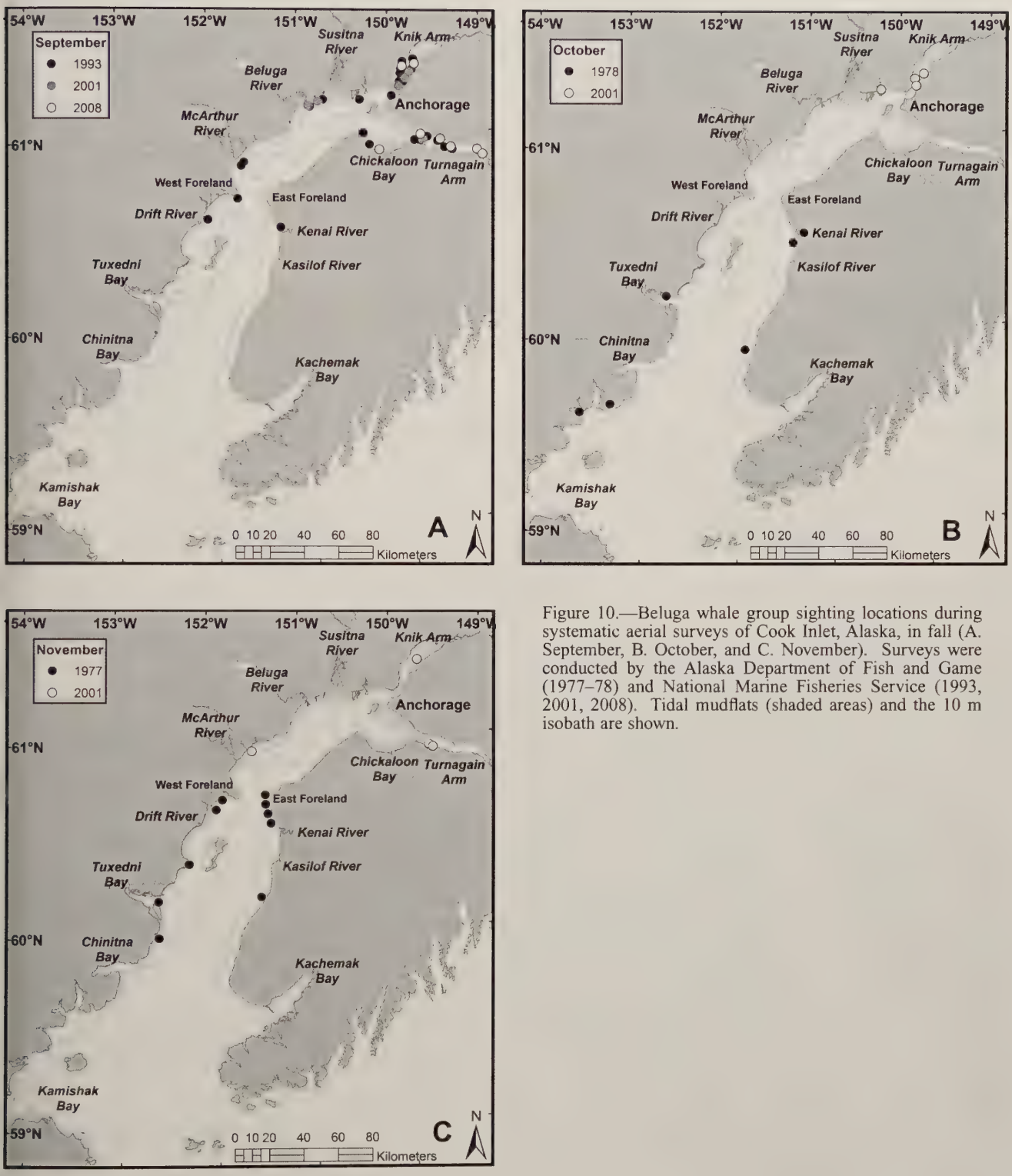
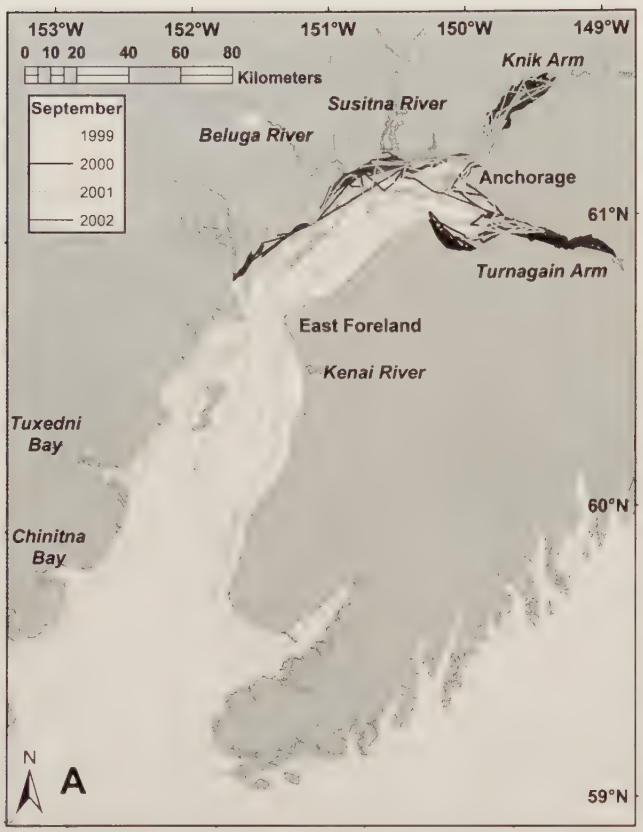
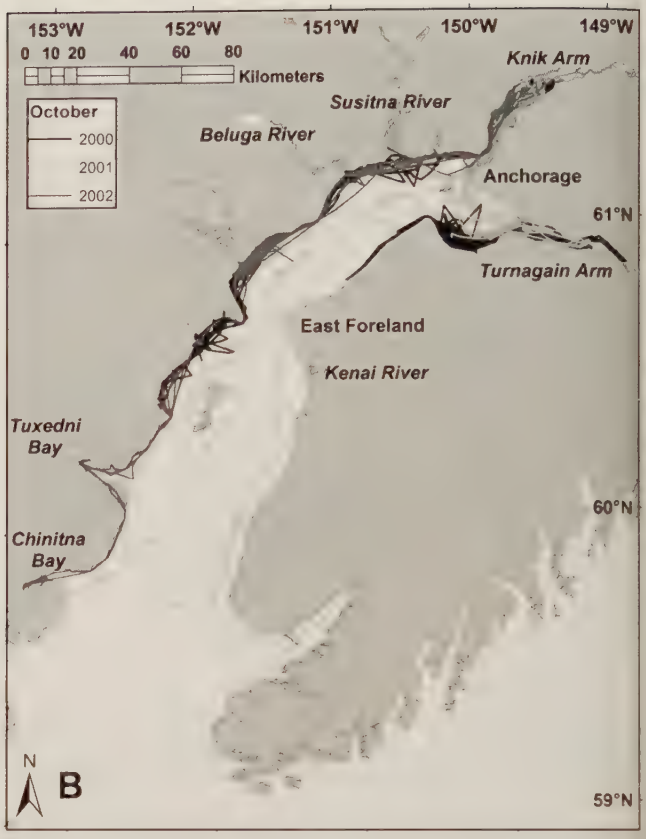


Figure 10.—Beluga whale group sighting locations during systematic aerial surveys of Cook Inlet, Alaska, in fall (A. September, B. October, and C. November). Surveys were conducted by the Alaska Department of Fish and Game (1977–78) and National Marine Fisheries Service (1993, 2001, 2008). Tidal mudflats (shaded areas) and the 10 m isobath are shown.





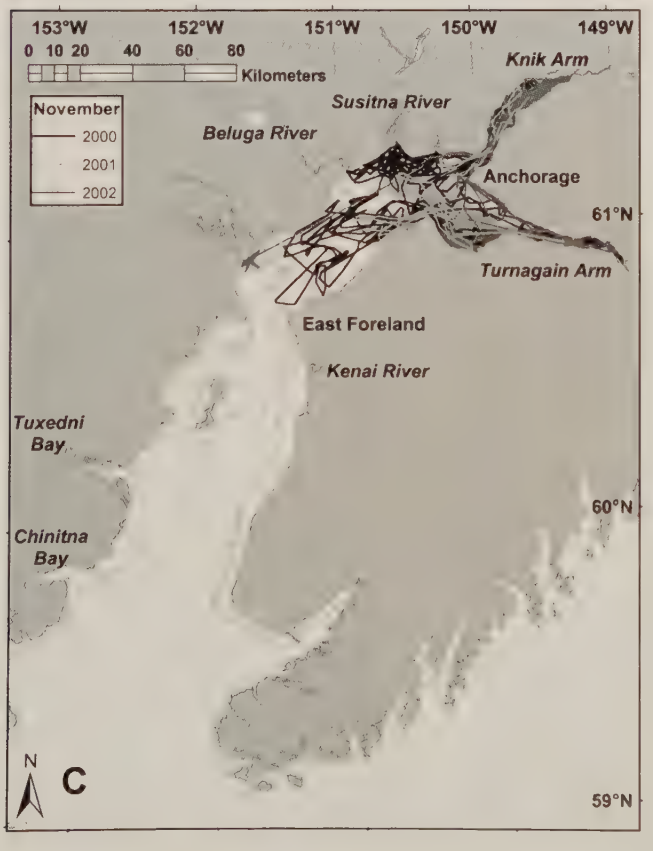


Figure 11.—Fall distribution of beluga whale satellite tag locations in Cook Inlet, Alaska, during: A. September 1999 (n = 1), 2000 (n = 2), 2001 (n = 6), and 2002 (n = 4); B. October 2000 (n = 2), 2001 (n = 6), and 2002 (n = 4); and C. November 2000 (n = 2), 2001 (n = 6), and 2002 (n = 3). See Appendix 3 for individual whale locations. Tidal mudflats (shaded areas) and the 10 m isobath are shown.

Overall, the number of CIBW opportunistic sightings began to decline from September to October in both upper and lower Cook Inlet (Table 3). With the exception of a single sighting in Kachemak Bay in 1976, all lower inlet sightings were during the period 1998 to 2010. Most were reported along the west side of the inlet (59%) in Redoubt, Tuxedni, Chinitna, Iliamna/Iniskin, and Kamishak bays. East side sightings were in or near Kenai River (36%). Upper inlet sightings were in areas occupied by whales during the summer months (Trading Bay (3%), Turnagain Arm (19%), Knik Arm (71%), Chickaloon Bay (4%), and the Susitna Delta (3%)) with almost all reported between 1999 and 2014 (two sightings occurred in Knik Arm in 1991).

November

Typically, ice begins to form in the upper inlet by November, and though there was no mention of ice during the one-day ADFG survey in 1977, and a note stated no whales were observed in upper Cook Inlet, all documented effort occurred in the lower inlet (Appendix 1). ADFG counted 41 whales[35] on 22 Nov. (Appendix 1) with 6 of the 10 sightings occurring south of East and West Foreland (Fig. 10c). By early November 2001, ice was present in Knik Arm, Turnagain Arm, Chickaloon Bay, and along the shore from Fire Island to Drift River during the NMFS survey (Rugh et al., 2004). Small numbers of whales were found in Turnagain Arm (3 and 6 whales), Knik Arm (14 whales), and Trading Bay (1 whale) on 9 Nov. (Fig. 10c).

All of the tagged whales transmitting locations in November (n = 11) remained in the upper inlet (Fig. 11c) and continued to travel within both Knik Arm and Turnagain Arm. One whale also explored deeper waters of the upper inlet, and another spent the first week of November in Trading Bay before returning to the Little Susitna River (Appendix 3). Tag transmissions overlapped with opportunistic sightings in 2000 and 2001, and aerial survey effort in 2001 (Table 4).

Similar to the systematic surveys, opportunistic sightings continued to decline from October to November (Table 3). Sightings occurred between 1999 and 2014, with the exception of one sighting at Kenai River in 1982 and one in Knik Arm in 1991. All CIBW opportunistic sightings in the lower inlet were in the Kenai River (63%), Kachemak Bay (25%), or Redoubt Bay (12%). Upper inlet sightings were in Knik Arm (93%), Turnagain Arm–Chickaloon Bay (3%), the Susitna Delta (2%), and Trading Bay (2%).

Fall Discussion

Some belugas move between the upper and lower inlet during the fall, as evidenced by one tagged whale during each year of the tagging study (Fig. 11a, b). NMFS surveys in 2001 continued to detect large numbers of whales in the upper inlet until November, when ice extent and concentration may have affected the ability of aerial observers to detect belugas. Dispersal of large numbers of whales into lower inlet waters in the fall was not evident in the later years of the NMFS surveys. Tagged whales still transmitting locations by the end of the fall had remained in or returned to the upper inlet (Fig. 11).

This differs markedly from surveys in the 1970's, when whales began to disperse into the lower inlet by midsummer. Although sightings occurred in the lower inlet during fall surveys in the 1970's, counts were low (41–75 whales) compared to the summer. It is possible that smaller, dispersed groups were harder to detect. In the early 1990's, whale groups appeared to disperse by late September (Withrow et al.[31]), though we have only one survey in the fall during this time period and no opportunistic sightings. By 2001, the contraction of this population's range into the upper reaches of Cook Inlet appeared to continue not only through the summer months but into the fall (Rugh et al., 2004; Shelden et al.[32]).

Winter

The winter period covers the months from December through February. Winter survey efforts and sightings, both systematic (Fig. 3, Fig. 12) and opportunistic (Table 3), were few compared to other seasons, in part because of weather and short day length. Nine of the satellite tags continued to transmit location data at the beginning of the season (Table 2), though only four were still functioning in February (Fig. 13; Appendix 3).

December

December was the only month with no aerial survey effort (Fig. 3). Data from nine satellite tags showed whales in the upper inlet and areas just south of East and West Foreland (Fig. 13a, Appendix 3). Belugas inhabited shallow, nearshore areas as well as deeper, mid-inlet waters, primarily in the region north of East and West Foreland and south of Point Possession. Only whales transmitting locations in 2000 and 2002 entered Knik Arm and Turnagain Arm during December (Appendix 3).

The CIBW Opportunistic Database included 16 sightings for the month of December (Table 3), all during the period 1999–2014. With the exception of one sighting of two whales at Kenai River in 2002, all sightings were in the upper inlet. Group sizes, when provided, ranged from 1 to 30 whales. Only one opportunistic sighting, on 17 Dec. 2001, coincided with locations transmitted from tagged whales (Table 4).

January

In 1978, during a survey flight that followed the ice edge (Appendix 1), belugas were found in three groups (12, 50, and 30 whales) in ice-free water south of Kasilof River (Fig. 12). On a series of mid-inlet tracklines on 22 Jan. 2002, belugas were in five small groups (15 whales total, Fig. 12) in sea ice ranging from 10% to 30% cover-

[35]Group sizes were not consistent between maps and table summaries: see Appendix 1 and Appendix 2, which are available in the online version of this article (doi: 10.7755/MFR.77.2.1).

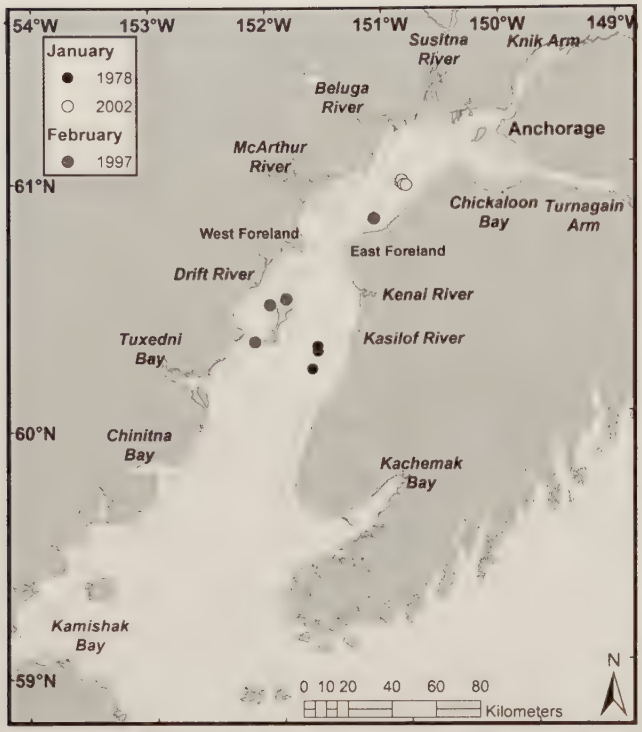


Figure 12.—Beluga whale group sighting locations during systematic aerial surveys of Cook Inlet, Alaska, in winter (January–February; surveys were not conducted in December). Surveys were conducted by the Alaska Department of Fish and Game (1978), Minerals Management Service (1997), and National Marine Fisheries Service (2002). Tidal mudflats (shaded areas) and the 10 m isobath are shown.

age (Rugh et al., 2004). None were found during the shoreline survey on 25 Jan. when "much of the area was ice-covered, making it difficult to find whales" (Rugh et al., 2004:9).

In January 2001, tagged whales remained south of the Susitna Delta (Fig. 13b, Appendix 3), never entering Knik Arm or Turnagain Arm where all CIBW opportunistic observations occurred. Tagged whales behaved similarly in January 2003. The three tagged whales travelled extensively between the Susitna Delta and East and West Foreland, often but not always together, crossing mid-inlet waters, and entering the lower inlet and returning to the upper inlet multiple times (Appendix 3). Only during January 2002 did a tagged whale spend any time in Knik Arm and Turnagain Arm (Appendix 3). Tag transmissions from this whale overlapped spatially and temporally with aerial survey effort and opportunistic sightings during the period 18–25 Jan. (Table 4).

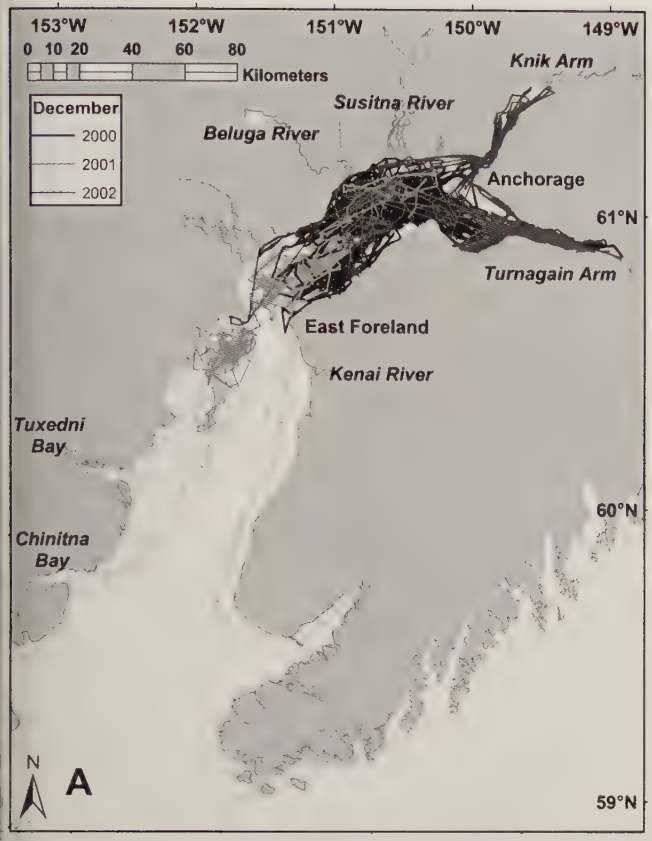
The CIBW Opportunistic Database included 17 sightings for the month of January, of which 13 occurred in the upper inlet (Table 3). Just over half of the upper inlet sightings were reported in Turnagain Arm, an area easily accessible by car. Average group size was 100–200 whales in the lower inlet during the 1980's and 2000's, and 3 to 15 whales, respectively, in the upper inlet during those same time periods (Table 3).

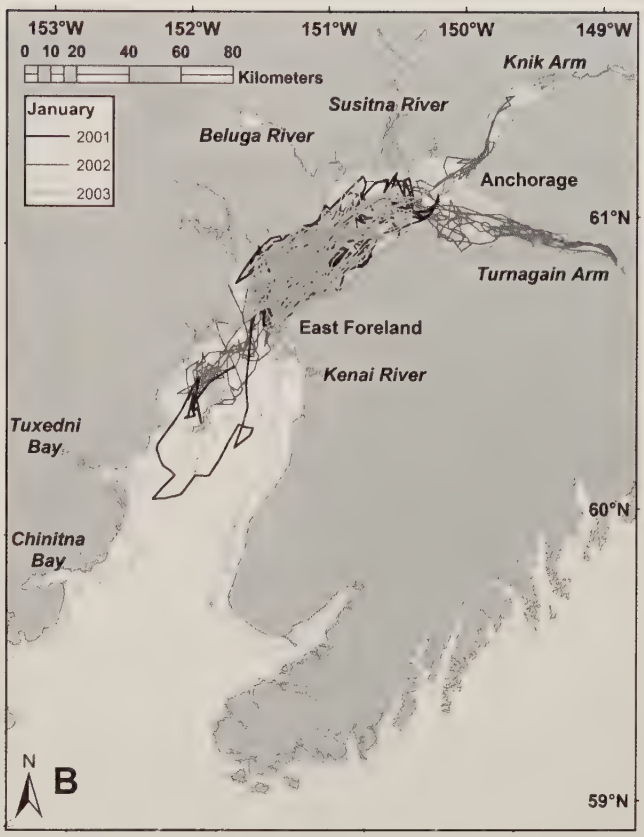
February

February surveys were flown by ADFG, MMS, and NMFS (Fig. 3). Belugas were not seen during ADFG surveys in 1979 (Appendix 1). Ice was present throughout much of the inlet and snow storms prevented exploration south of Kachemak Bay on 25 Feb. In 1997, MMS observers saw belugas on 12 and 28 Feb. (Fig. 12, Table 1), but not on 15 Feb. despite thorough coastal coverage south to Chinitna Bay and Ninilchik (Hansen and Hubbard[17]). Hansen and Hubbard[17] reported that ice conditions near Kalgin Island ranged from 40% to 60% coverage in mid-February to open water by late February. The authors noted "the presence of extensive shorefast ice at the mouth of the Susitna River and other major streams made it difficult to see if whales were in these areas" (p. 13). Belugas were not seen during NMFS aerial surveys on 25–26 Feb. 2002 (Rugh et al., 2004). Ice covered much of the survey area, in the range of 70% to 100% coverage mid-inlet and in Knik Arm and Turnagain Arm, with areas of open water (50% coverage) just south of the Susitna River.

During February 2002, the last whale transmitting locations moved from Knik Arm into mid-inlet waters before entering the lower inlet (Fig. 13c, Appendix 3). Transmissions overlapped with areas surveyed by the aerial team (Table 4). Three whales tagged in 2002, all males, continued to transmit positions in February 2003 (Fig. 13c). One young male beluga frequented Turnagain Arm and joined another young male in Knik Arm (Appendix 3). The three whales moved throughout upper inlet waters before travelling south of East and West Foreland in mid-February (Appendix 3). Tag transmissions from two of these three whales were in the vicinity of an opportunistic sighting (Table 4).

No CIBW opportunistic sightings were reported in February during the 1970's, 1980's, or 1990's (Table 3). Nine of the eleven CIBW opportunistic sightings reported in February between 2001 and 2014 were in the upper inlet in Trading Bay (56%), Turnagain Arm (22%), and Knik Arm near the Port of Anchorage (22%). Lower inlet sighting included 50 whales near Drift River in Redoubt Bay and a lone whale in the Kenai River (Table 3).





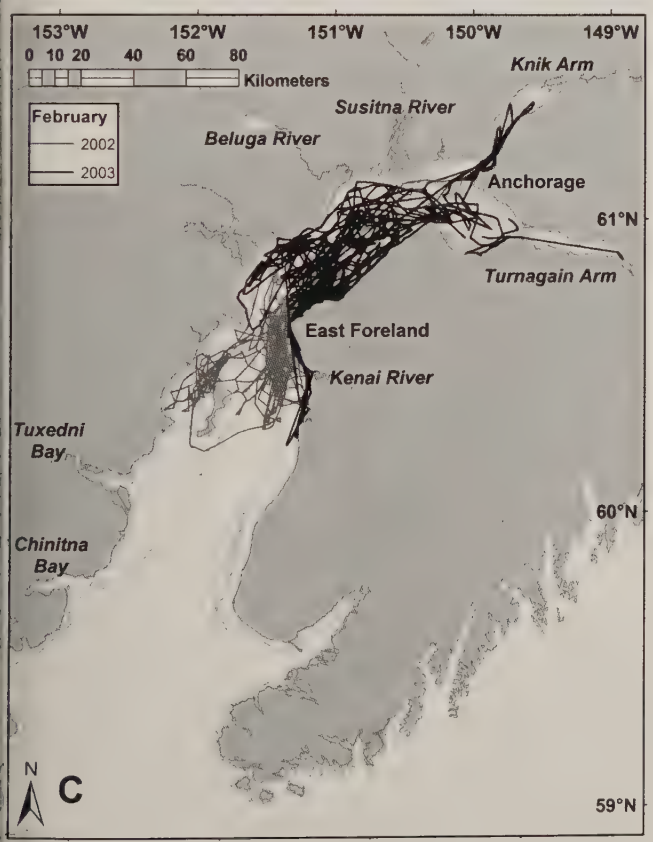


Figure 13.—Winter distribution of beluga whale satellite tag locations in Cook Inlet, Alaska, during: A. December 2000 (n = 2), 2001 (n = 4), and 2002 (n = 3); B. January 2001 (n = 2), 2002 (n = 2), and 2003 (n = 3); and C. February 2002 (n = 1) and 2003 (n = 3). See Appendix 3 for individual whale locations. Tidal mudflats (shaded areas) and the 10 m isobath are shown.

Winter Discussion

Winters in Cook Inlet are characterized by short day lengths and ice-covered waters. Despite the possibility of ice entrapment, CIBWs remained in upper inlet waters particularly during the later time period (Rugh et al., 2004; Hobbs et al., 2005; Goetz et al.[18]). Large tidal fluctuations create a dynamic ice environment such that whales were able to access the upper reaches of Knik Arm and Turnagain Arm during the winter period. Although whales transmitting locations in 2001 never entered these areas, opportunistic sightings confirmed whales were present.

Goetz et al.[18] found that movements of tagged belugas were influenced by the presence of ice in Cook Inlet during the winter. After examining the biweekly proportion of ice type (ranging from very open pack to compact ice) throughout the inlet, from Dec. 2001–Mar. 2002 and Dec. 2002–Apr. 2003, total ice cover was always less than 50% for every 2-week period. When ice was present, belugas were most commonly found in open pack ice (winter of 2001–02) and very open pack ice (winter of 2002–03). During the winter of 2001–02, belugas ($n = 2$) preferred open water only 2% of the time when ice was present compared to 30% during the winter of 2002–03 ($n = 3$). On most occasions when belugas preferred open water, ice covered less than 10% of Cook Inlet.

In addition to this close association with ice, diving was another behavior that may have confounded detection during winter aerial surveys. Preliminary analyses of the tag data indicate whales were diving deeper and longer during the period December–May compared to the period June–November (Goetz et al.[18]). Average depth (m) and duration (minutes) increased almost three times, from 3.0 m (SD = 4.7) to 8.2 m (SD = 12.3) and 1.6 minutes (SD = 1.9) to 5.2 minutes (SD = 5.5) for the 11 whales equipped with ST-16 tags (Goetz et al.[18]:19).

The combination of poor sighting conditions (low light levels in winter and white whales among ice floes) and whale behavior (close association with ice, longer, deeper diving patterns, and smaller groups) made it difficult to ground truth or even detect groups during this season. This was most evident during the NMFS survey that overlapped with tagged whale locations and detected whales in January but not in February. Combining satellite-tagging with real-time acoustic monitoring and aerial ground truthing may be the best option for quantifying habitat use patterns and visual detectability during winter.

Spring

During spring (Mar.–Apr.–May), ice is still present in Cook Inlet. By March, ice cover has reached its maximum extent and begins to recede and melt through March and April. Spring survey efforts and sighting reports, both systematic (Fig. 3, Fig. 14) and opportunistic (Table 3), increased throughout the season. Four tags continued to transmit whale locations at the beginning of the season (Fig. 15), though by May, as aerial survey effort increased, only one tag continued to function (in 2003). Tagging of an adult male beluga in 1999 occurred on the last day of May (Table 2, Appendix 3).

March

Belugas were found on both aerial survey days in 1978 and one of the two survey days in 1979 (Appendix 1). The number of whales counted in 1978 ranged from 43 (5 sightings) on 1 Mar. to 146 (17 sightings) on 2 Mar., compared to the lone group of 11 whales seen mid-inlet in 1979 (Fig. 14a). Ice appeared to be more prevalent in the inlet in 1979; maps showed ice along the shore in the lower inlet and near Kalgin Island in mid-March, vs. 1978 when the northernmost areas of the upper inlet had large expanses of open water by early March.

The survey area was ice free during the 1997 aerial surveys (Hansen and Hubbard[17]). Sighting locations, number of sightings, and group sizes were similar to those observed during the MMS February surveys (Fig. 14a, Table 1). NMFS did not fly surveys in March 2002, however, it was noted during the April survey that ice still covered much of the upper inlet (Rugh et al., 2004).

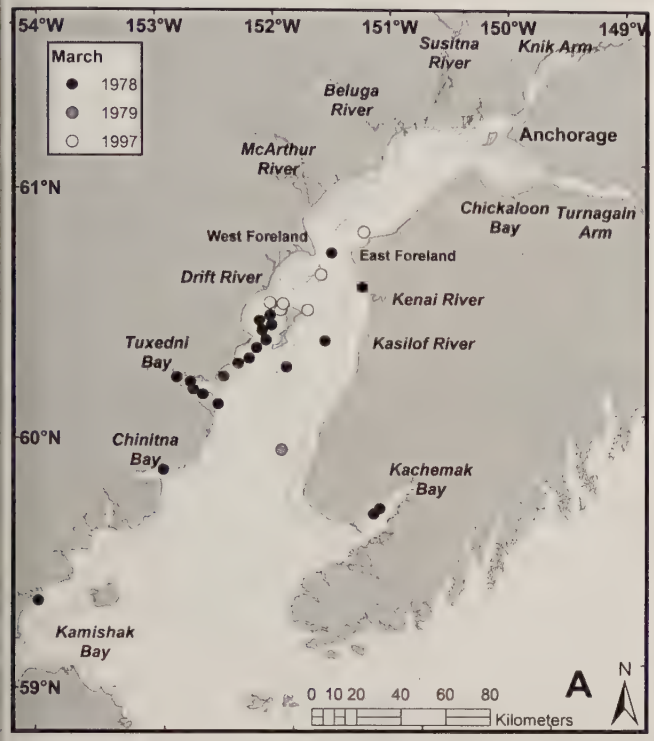
The last tag transmitting in 2002 stopped on 9 Mar.; at the time, the male beluga was in the lower inlet in waters north and west of Kalgin Island (Fig. 15a, Appendix 3). Similar to behaviors observed during the winter months, the three male whales transmitting locations in 2003 continued to travel extensively in mid-inlet waters north of East and West Foreland (Fig. 15a, Appendix 3).

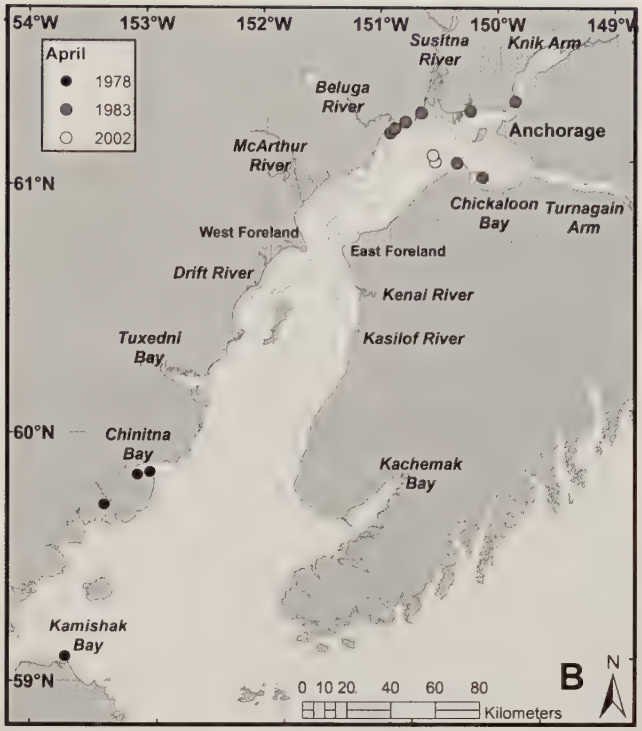
All CIBW opportunistic sightings in the lower inlet (Table 3) were between Ninilchik and the Kenai River. None of the opportunistic sightings in the upper or lower inlet overlapped with tagged whale locations. Most upper inlet sightings were reported in Turnagain Arm (29%) and Knik Arm (62%), with lone sightings in Trading Bay (1 whale) and near Tyonek (22 whales).

April

The 1978 aerial surveys occurred in the lower inlet (Appendix 1), while the 1983 surveys were restricted to the upper inlet north of North Foreland and Moose Point (Appendix 2). In 1978, beluga whales were found in roughly five groups (about 56 whales total[35]) in bays along the west side of the lower inlet (Fig. 14b). Four groups were observed on each survey day in 1983 (6 Apr.: $n = 10$ whales; 28 Apr.: $n = 38$ whales[35]) (Fig. 14b). In contrast to the ADFG surveys, ice covered much of the upper inlet during NMFS surveys conducted 2–3 Apr. 2002 (Rugh et al., 2004). Two groups (8 and 10 whales) were found on mid-inlet transects on 2 Apr., while none were found during the coastal surveys on 3 Apr., despite fair to excellent viewing conditions.

By April 2003, only two whales were transmitting locations. One tag stopped transmitting near the Susitna River on 1 Apr. (Appendix 3). Hobbs et al. (2005) did not analyze tag data collected after March, as only one whale continued to transmit locations





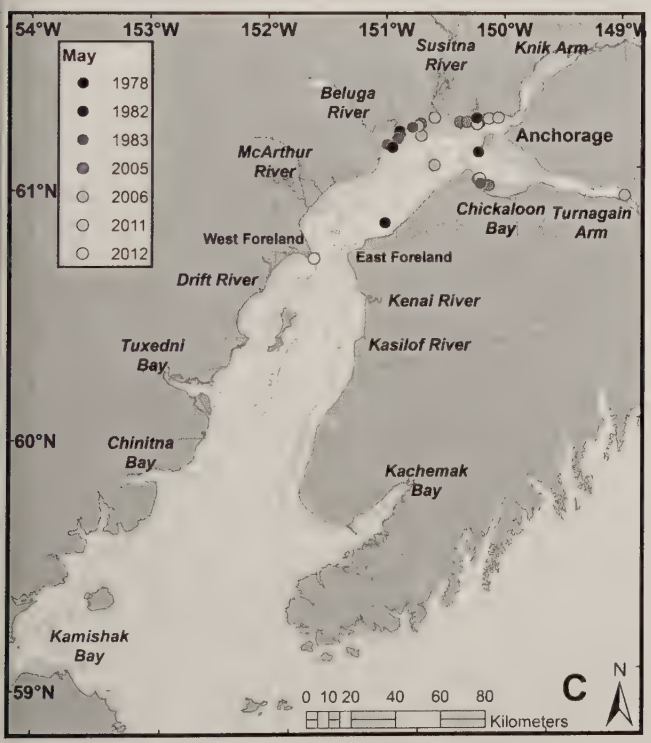


Figure 14.—Beluga whale group sighting locations during systematic aerial surveys of Cook Inlet, Alaska, in spring (A. March, B. April, and C. May). Surveys were conducted by the Alaska Department of Fish and Game (1978–79, 1982–83), Minerals Management Service (1997), and National Marine Fisheries Service (2002–12).

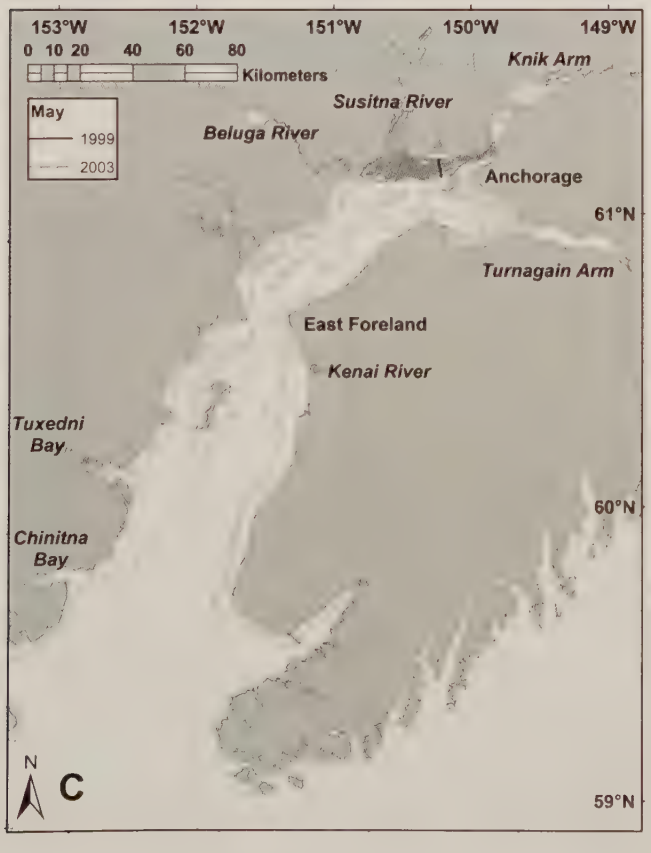


Figure 15.—Spring distribution of beluga whale satellite tag locations in Cook Inlet, Alaska, during: A. March 2002 (n = 1) and 2003 (n = 3); B. April 2003 (n = 2); and C. May 1999 (n = 1) and 2003 (n = 1). See Appendix 3 for individual whale locations. Tidal mudflats (shaded areas) and the 10 m isobath are shown.

through April and most of May. That whale remained in the upper inlet for the entire month, travelling between Knik Arm, Turnagain Arm, and the Susitna Delta (Fig. 15b, Appendix 3).

CIBW opportunistic sightings increased substantially from March to April (Table 3), though none coincided with aerial survey effort or tag transmissions. Lower inlet sightings prior to 2000 (Table 3, $n = 14$), with the exception of one sighting in the Kenai River, were on the west side of the inlet in or near Illiamna/Iniskin (57%) or Kamishak (36%) bays. Since then, all opportunistic sightings have been reported in or just north of the Kasilof ($n = 4$) and Kenai rivers ($n = 32$), or in Redoubt Bay ($n = 1$). In the upper inlet, sightings were reported during all time periods with groups ranging from 1 to 25 whales. Most sightings occurred in the Susitna Delta (27%), Turnagain Arm/Chickaloon Bay (37%), and Knik Arm (30%), with a few in Trading Bay (5%) and near East Foreland (1%).

May

Aerial surveys occurred in May during 7 of the 25 aerial survey years (Fig. 3, Fig. 14c), in part, because NMFS abundance surveys began near the end of May before continuing into June (which is also reflected in the low number of effort hours during May: Fig. 3). In 1978, ADFG found only two groups (20 and 7 whales) in the upper inlet on 22 May (Appendix 1), while upper inlet surveys in the early 1980's documented large numbers of belugas north of Threemile Creek and Moose Point (Appendix 2). Three groups were seen each year with counts ranging from 45 (17 May 1982) to 262 whales (27 May 1983).

In 2005, the NMFS abundance survey began on the last day of May (Shelden et al., 2013). Belugas were found in Chickaloon Bay (37 whales) and in the Susitna Delta near the Ivan River (229 whales) and the Little Susitna River (7 whales) during a survey that included coastal waters north of the Kenai River and West Foreland (Shelden et al., 2013). In contrast, a NMFS survey of the upper inlet conducted in early May 2006 (Rugh et al.[22]) found only small numbers of whales: four sightings (18 whales total) on 2 May and six sightings (25 whales total) on 3 May (Fig. 14c). Broken ice was present in the Susitna River in early May 2006 (Rugh et al.[22]), but had melted away by the time the NMFS abundance survey began on 6 June (Shelden et al., 2013), and 296 whales (11 groups) were found in the upper inlet that day.

Similar to 2005, the abundance surveys in 2011 and 2012 included days at the end of May (Shelden et al., 2013). Two groups of belugas were found during the upper inlet survey on 31 May 2011: in Chickaloon Bay (57 whales) and the mouth of the Little Susitna River (200 whales) (Fig. 14c). Three days of lower inlet surveys occurred in May during the 2012 survey (Shelden et al., 2013). About seven belugas were found near West Foreland headed toward Trading Bay on 31 May (Fig. 14c). Whales were seen in Trading Bay on subsequent survey days (see Summer section and Fig. 5e).

On the last day of May in 1999, NMFS tagged a beluga whale near the Little Susitna River (Fig. 15c). This whale remained in the Susitna Delta until the end of July (see Summer section). In 2003, locations from the last remaining tag show the whale travelled back and forth between the Beluga River and Knik Arm before transmissions ended on 25 May (Fig. 15c, Appendix 3). Tag transmissions coincided with one CIBW opportunistic sighting on 31 May 1999 (Table 4).

CIBW opportunistic sightings increased in the upper inlet and declined in the lower inlet from April to May (Table 3). Lower inlet sightings prior to 2000 ($n = 2$) were in Kachemak or Iniskin bays, while the remaining opportunistic reports occurred in the Kenai River almost annually since 2007.

Spring Discussion

Similar to winter, the year-to-year variability in ice extent and concentration appeared to affect the ability of aerial observers to detect beluga whales during the spring. In spring, when the ice breakup begins, whales gather together as they regain access to river mouths. In early spring, whales continued to move throughout mid-inlet waters. Not until late spring and early summer, when anadromous fish return to natal streams, did whale behaviors shift to longer surfacing periods and shallower diving patterns (Hobbs et al., 2015a; Goetz et al.[18]). Group sizes tended to be smaller in spring, until the end of May when whales began to coalesce into larger groups at the river mouths. Most aerial survey and opportunistic sightings, and all tag locations, were in the upper inlet by May.

Conclusions

Cook Inlet is a complex and dynamic environment, covered in ice part of the year and opaque waters year-round that confound detection of beluga whales. This review of the tremendous amount of survey effort undertaken thus far shows how little we still know outside of the open water season and early summer period. Based on available information from aerial surveys, tagged whales, and opportunistic sightings, these whales show a preference for waters in the upper portion of Cook Inlet, and when the population declined (Hobbs et al., 2015a), the distribution of animals became more concentrated in the northern region (Rugh et al., 2010). Although belugas do inhabit mid-inlet waters and bays in the lower inlet, sightings south of East and West Foreland have been relatively rare in the past two decades. This contraction in range was observed not only during the summer months (Rugh et al., 2000; 2010) but also into the fall during the later period of this seasonal study (Rugh et al., 2004; Shelden et al.[32]). There has also been a shift away from Knik Arm in early June, observed since 2008, but this area was not abandoned entirely as whales were observed there in August. It is unknown if this contracted distribution is a result of changing habitat (Moore et al., 2000; Norman et al., 2015), prey concentration, or predator avoidance

(Shelden et al., 2003), or if it could be explained as the contraction of a reduced population into a small number of preferred habitat areas (Rugh et al., 2010; Goetz et al., 2007, 2012).

Remaining in the upper inlet exposes beluga whales to potential natural and anthropogenic threats such as ice entrapment, stranding, vessel traffic, coastal development projects, dredging, and increased proximity to urban runoff and waste from the largest city in Alaska, Anchorage (Norman et al., 2015). Contraction of the population into the upper inlet, not only during early summer (Rugh et al. 2010) but also throughout the year, may increase vulnerability to catastrophic events and localized group mortality events (Hobbs et al., 2015c). Live strandings are not uncommon for this population, when they become trapped on the upper inlet mudflats on the ebbing tide. And although the whales refloat and swim off on the incoming tide, prolonged stranding could compromise survival (Vos and Shelden, 2005; Burek-Huntington et al., 2015).

Habitat associations during the early summer period have been studied, and note "beluga presence was negatively associated with sources of anthropogenic disturbance and positively associated with fish availability and access to tidal flats and sandy substrate" (Goetz et al., 2012). These predicted habitats varied depending on whale group size, where larger groups were more closely tied to tidal flats and high flow rivers (a proxy for suitable habitat for anadromous fish). Distributions predicted in Goetz et al. (2012) were similar to those observed during the late 1970's, possibly indicating that as this population recovers it may reoccupy these areas.

Based on our review, additional studies are needed to better quantify habitat use patterns during seasons other than early summer. Acoustic monitoring studies are underway in Cook Inlet, attempting to detect whales year-round (Castellote et al., 2011). However, these studies depend on animals vocalizing to determine presence. Combining satellite-tagging with real-time acoustic monitoring and aerial ground truthing may be the best option for quantifying habitat use patterns and visual detectability particularly during ice-covered seasons.

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Socio-sexual and Probable Mating Behavior of Cook Inlet Beluga Whales, *Delphinapterus leucas*, Observed From an Aircraft

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Introduction

Socio-sexual behavioral interactions among free-ranging beluga whales, *Delphinapterus leucas,* have not been previously documented, to our knowledge, and are thus poorly understood. Although mating and social behaviors have been described for captive beluga whales (Hill et al., 2015), it is logistically difficult to observe undisturbed behavior among free-ranging beluga. They inhabit remote, and in the case of the Cook Inlet beluga whale (CIBW), typically muddy waters. Observations of socio-sexual behaviors of free-ranging CIBW are needed to address critical information gaps on the natural history, mating behavior, and potential behavioral habitat preference of this declining insular population.

Little is known about the mating behavior or mating season of beluga whales in the wild. Reported age of sexual maturity varies from 4 to 10 years for females and 8 to 15 years for males (Nowak, 1991; Suydam et al.[1]). Gestation is 14.0–14.5 months, with a single calf born in late spring or early summer (Sergeant, 1973). This would suggest mating occurs in early spring. In autumn, beluga whale populations migrate toward a few common wintering grounds in Bering Sea offshore waters characterized by unconsolidated pack ice where mating is believed to occur during late winter or early spring (Brodie, 1971; Sergeant, 1973; Brown Gladden et al., 1997).

Unlike the Arctic stocks, the Cook Inlet beluga population is not thought to undertake seasonal migrations outside of Cook Inlet (Laidre et al., 2000; Rugh et al., 2000). Specific breeding areas are unknown or possibly nonexistent (i.e. mating might occur anywhere throughout their range). Similar to Arctic beluga populations, CIBW calving is believed to occur in early summer (Hobbs et al., 2015a) although Native hunters have observed newborn CIBW calves from April through August (Huntington, 2000).

Alaska natives described CIBW calving areas as the northern side of Kachemak Bay in April and May, off the Beluga and Susitna River mouths in May, and in Chickaloon Bay and Turnagain Arm during summer (Huntington, 2000). McGuire et al.[2], during vessel-based surveys of the upper reaches of Cook Inlet in 2005–07, did not document any specific calving locations or a definitive calving season and calves were encountered in all surveyed location and months (April–October). Thus CIBW are reported to continue to calve later in the season than the Arctic stocks, although their calving season is unclear. In part, some confusion on calving dates may be a function of sightings of calves well into the summer that were actually born weeks or months earlier.

Global observations of both wild and captive beluga whales indicate that breeding is seasonal. Among captive beluga whales, Robeck et al. (2005) reported that both testosterone in males and progesterone in females were elevated during late winter/ear-

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ABSTRACT—Socio-sexual and mating behaviors, to our knowledge, have not been previously documented among free-ranging beluga whales, Delphinapterus leucas, *but they have been described in detail for captive belugas. We report on the first photo-documented interaction and display of socio-sexual and apparent mating behavior of noncaptive beluga whales in Cook Inlet, Alaska. This behavior was seen on two different days in the same river mouth in uncharacteristically clear waters of upper Cook Inlet. On 24 April 2014, social and possible mating behaviors were observed and photographed for approximately 12 min within a group of nine adult beluga whales in the mouth of Middle River on the west central side of Cook Inlet. A total of 136 photographs were taken at a radial distance > 500 m. On 7 May 2014, similar behaviors were observed among four adult beluga whales in the same location for about 7 min. The second group was not photo-documented due to flight limitations. In both circumstances, affiliative behavioral events such as echelon and contact swimming, and socio-sexual behaviors such as ventrum-to-ventrum contact, ventral presentations, pelvic thrusting, nodding, and rubbing were observed. These behaviors resemble those previously reported for captive beluga mating behaviors and copulation. Similarities between these observations with captive mating behaviors, and the timing of ovulation and peak calving periods from other wild beluga populations, provide strong evidence that mating occurs during early spring months in Cook Inlet.*

ly spring, peaking in March (Robeck et al., 2005). These combined studies suggest that breeding should peak seasonally among CIBW as well, although there are no reported behavioral, hormonal, or reproductive data to support this, in part because aerial surveys and sampling of whales rarely occur in March in Cook Inlet (Shelden et al., 2015).

Among captive belugas and bottlenose dolphins, *Tursiops truncatus*, ethograms for social behavior have been successfully developed and applied to link descriptive behavioral events with social (e.g., affiliative, sexual) relationships (Östman, 1991; Recchia[3]). Recchia[3] applied a set of social behaviors specific to captive beluga whales by defining an actor and recipient and their dyadic (i.e., pair) interactions to quantitatively assess dominance among five animals of both sexes. Behaviors included ventrum-to-ventrum contact, thrusting, ventral presenting, rubbing, and nodding (Table 1; Recchia[3]). A clear correlation between size of animal and dominance was found, with larger animals most often in an actor role and more dominant to smaller animals in the group, regardless of sex (Recchia[3]).

Glabiky et al., (2010) found that male-to-female thrusting between captive-born juvenile beluga whales and wild-caught animals from the Chukchi Sea varied significantly across months. However, a clear peak in activity was found during March–May, suggesting seasonality in sexual behaviors (Glabiky et al., 2010).

Herein, we describe the first documented interaction and display of socio-sexual behavior among free-ranging CIBW during late spring. This behavior was observed on two different days in the same river mouth, one time documented with photographs. These data support the hypothesis that CIBW mating occurs during early spring months, similar to other regions.

Table 1.—Definitions of affiliative and socio-sexual behavioral events observed, adapted from Recchia (text footnote 3) and Hill et al. (2015).

Behavioral Event	Abbreviation	Definition
Affiliative		
Contact	C	Actor contacted recipient and did not rub. Contacts could involve virtually any part of actor's and recipient's bodies.
Contact Swim	CS	Actor contacted recipient and contact was maintained for > 3 seconds (s).
Echelon Swim	ES	Actor altered his/her swim pattern to swim in parallel with recipient, maintaining relative position to recipient for > 3 s, within 3 m (1 body length).
Socio-sexual		
Ventrum-to-Ventrum Contact	VVC	Contact in which the actor brought his/her genital region into contact with recipient's genital region.
Ventral Present	VP	Actor rolled his/her body towards recipient, so the ventral region pointed at recipient.
Thrust	Th	Actor formed an "S" shape with his/her body, with head and genital region moved ventrally and tail moved dorsally, and moved genital region towards recipient, < 3 m (1 body length) of each other. Usually occurred when two animals were swimming in parallel. A mutual thrust was scored when two animals directed this behavior at each other simultaneously.
Ventral Swim	VS	Type of echelon swim in which actor maintained a ventral present towards recipient for > 3 s. A mutual ventral swim was scored when two animals swam in parallel with their genital regions pointed at each other for > 3 s.
Nodding	Nd	Actor, while facing recipient, repeatedly and rapidly moved his/her head up and down slightly.
Rub	Rb	Extended form of contact in which actor rubbed part of his/her body against recipient. Often took form of actor approaching recipient and rubbing most of body length against the back or side of recipient. Recipient sometimes facilitated rub, e.g., by arching back slightly.

Methods

Apache Alaska Corporation funded aerial surveys, conducted by Smultea Environmental Sciences[4] in Cook Inlet, Alaska, from 1 Apr–27 June 2014. The surveys were part of a marine mammal monitoring program during seismic operations funded by Apache Alaska Corporation. The aerial surveys were designed to monitor the distribution and habitat-use patterns of CIBW in upper Cook Inlet. Aerial surveys were flown from a high-wing, single-engine Cessna 172. The general aerial route lasted 2.5–3 h, departing Anchorage, transiting west across Knik Arm, then flying about 1.6 km offshore along western Cook Inlet through the Susitna River Delta south to West Foreland. The route continued to the eastern side of Cook Inlet by crossing to East Foreland, then transiting along the eastern coastline through Chickaloon Bay and returned to Anchorage.

The survey was flown at an altitude of 305 m and speed of about 95 kn. Whales were circled to document group size and composition at a radial distance of >457 m to remain outside the aircraft's air-to-water sound transmission range relative to the sighting location (Urick, 1972; Richardson et al., 1995). While circling, sightings were documented with a high-definition (HD) Canon EOS 7D Digital SLR camera with a Canon 100–400 mm image stabilized (IS) telephoto lens.

Systematic behavioral protocol and descriptive notes were recorded on a laptop computer using real-time Mysticetus observational software (Smultea and Bacon[5]). Recorded data,

[3]Recchia, C. A. Social behaviour of captive belugas, *Delphinapterus leucas*. Rep. no. WHOI-94-03. Woods Hole Oceanographic Institute, MA, 1994, 206 p.

[4]Mention of the trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA

[5]Smultea, M. A., and C. M. Bacon. 2012. A comprehensive report of aerial marine mammal monitoring in the Southern California Range Complex: 2008–2012. Prep. for Commander, U.S. Pacific Fleet, Pearl Harbor, Hawaii. Submitted to Naval Facilities Engineering Command Southwest (NAVFAC SW), EV5

Figure 1.—Upper Cook Inlet showing locations of the two observations of beluga whales involving socio-sexual behavior on 24 April and 7 May 2014.

including photographs, were used to later categorize behaviors following definitions of affiliative and socio-sexual behavioral events for captive beluga whales described by Recchia[3] (Table 1).

Results

Mating Encounter First Observed

On 24 April 2014, we (KLM and MC) observed and took 136 photographs of an interaction between a group of nine adult beluga whales approximately 15 km northeast of the McArthur River and about 0.5 km offshore of western Cook Inlet, over waters about 10 m deep relative to the mid-tide at the time (Fig. 1). The plane circled the group for about 12 min as the whales slowly traveled southeast and parallel to shore. Individual whales were intermittently visible at the surface between surfacing bouts within the brown-colored, silt-filled water that limited visibility below the water surface.

Water clarity, and thus visibility of whales below the water surface, improved as the whales neared the Middle River mouth. During this encounter, three animals remained on the periphery about 10 body lengths from the other six whales in the group. The latter six whales were paired into three groups of two animals (Figs. 2–9), and all three pairs displayed socio-sexual behavioral events described for captive mating belugas by Recchia[3]. Aspects of these inter-animal interactions most relevant to the behaviors identified in Table 1 are detailed chronologically in Table 2.

Mating Encounter Second Observed

On 7 May 2014, similar socio-sexual behavioral events were observed among four adult beluga whales (by MAS) approximately 1 km north of the McArthur River and about 1 km offshore of western Cook Inlet near the Middle River mouth (Fig. 1). The group was circled for about 7 min, a relatively short duration due to flight and survey limitations.

The socio-sexual behaviors observed and documented in field notes included repeated ventral-to-ventral contact, ventral presents, thrusting, nodding, and touching. In addition, two whales chased and appeared to maneuver for proximity to a third central animal. No photographs were taken during this encounter, because an HD camera and zoom lens were not available.

Environmental, San Diego, under Contr. No. N62470-10-D-3011 issued to HDR, Inc., San Diego, Calif., 68 p.

Figure 2.—Pair 1, two animals observed swimming within one body length of each other through silty water. Photo by Mark Cotter.

Figure 3.—Pair 1, exhibiting contact swimming. Photo by Mark Cotter.

Discussion

Sexual activity has not previously been described for CIBW in the wild despite extensive aerial surveys conducted in the region since 1994 (Rugh et al., 2000, 2004, 2005; Shelden et al., 2013, 2015) and additional vessel- and shore-based marine mammal monitoring programs in Cook Inlet (McGuire et al.[2]). The lack of recorded observations during these surveys indicating sexual activity among belugas may in part be due to timing—almost no surveys were conducted during early spring when the CIBW are likely mating (Shelden et al., 2015). Underwater observations of beluga behavior and direct observations of inter-individual behavior are difficult to obtain and limited given the challenges inherent with remote, and typically silty waters characterizing Cook Inlet. Observations reported herein are exceptional in that the beluga whales were in a freshwater confluence area, allowing unusually clear identification of subsurface behavioral events, including relative inter-individual spacing and positioning from the aerial, three-dimensional view of the whales.

To our knowledge, the socio-sexual behavioral events we observed in Cook Inlet on 24 April and 7 May 2014 have never been photo-documented among free-ranging beluga whales and specifically the CIBW population. However, these behaviors closely resemble the specific behavioral events of previously observed beluga whales courting and mating in captivity (Hill et al., 2015). The seasonality of these apparent courting and mating behaviors in CIBW correspond with reported spring mating seasons for the Arctic populations (Burns and Seaman[6]) as well as captive belugas (Robeck et al., 2005).

Correlation of our observations with timing of ovulation, peak testes size, and peak calving periods from both captive and other wild beluga populations provide strong evidence that mating occurs during early spring months in Cook Inlet. This suggests that the CIBW population exhibits seasonal fluctuations in behavioral ecology.

The distribution, habitat use, and grouping behavior patterns of mammals have been linked with ecological parameters such as food and mate availability or distribution and predator avoidance (Davies et al., 2012; Kappeler et al., 2013). Both of our reported beluga whale sightings occurred in the same general area, suggesting importance of this area.

All the beluga whales we observed in the two groups described herein were white and of similar body size. Coloration in beluga whales is related to physical maturity; however, Burns and Seaman[6] reported females may retain some degree of gray coloration upwards of 21 years and McGuire et al.[2] reported 10 photo-identified mothers that retained gray coloration, suggesting that coloration is not definitive of maturity. It is estimated that female belugas reach sexual maturity when they are 4–9 years old and males when they are 4–7 years old (Suydam, 2009). Therefore, it is likely that belugas may become sexually mature before they have turned completely white.

Although all the belugas we observed were white and appeared to be adults based on body size, we were not able to determine their sex from our aerial observations. It is possible that this socio-sexual activity represents play and or social behaviors of indifferent gender or non-reproductive animals, or out of estrus. It is also possible that socio-sexual activity occurs year-round and was only coincidental-

[6]Burns, J. J., and G. A. Seaman. 1986. Investigations of belukha whales in coastal waters of western and northern Alaska. II. Biology and ecology. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 56(1988): 221–357.

Figure 4.—Pair 2 slowly rolling around each other in physical contact, creating large plumes of silt and presented ventral sides. Photo by Mark Cotter.

Figure 5.—Pair 3 exhibiting contact swimming necks and heads both cocked inwards facing each other, nodding and almost touching. Photo by Mark Cotter.

Figure 6.—Pair 3 exhibiting contact swimming and nodding, one animal rotated onto its side with ventral facing towards the other beluga. Photo by Mark Cotter.

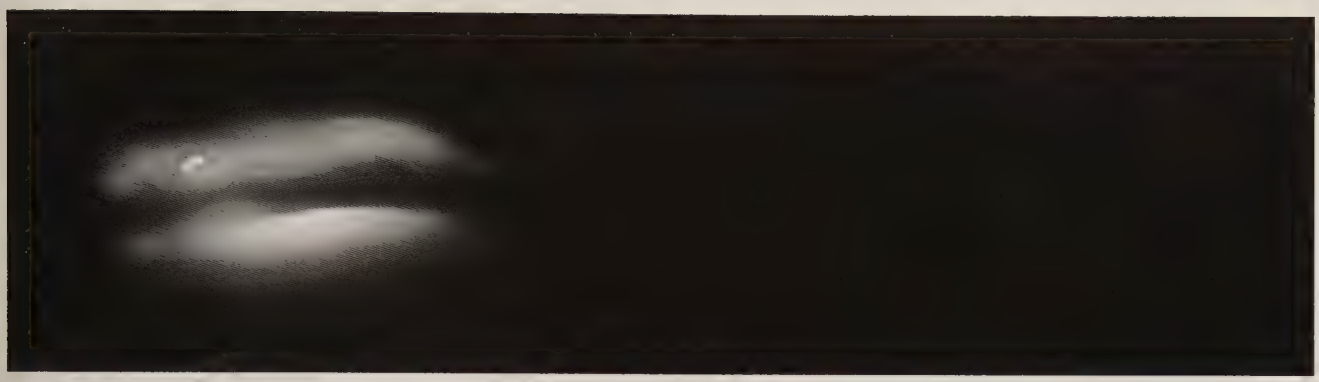

Figure 7.—Pair 3 exhibiting ventral presenting and pelvic thrusting. Photo by Mark Cotter.

Figure 8.—Pair 1 exhibiting ventral presenting, pelvic thrusting, and contact swimming. Photo by Mark Cotter.

Figure 9.—Pair 3 continuing pelvic thrusting, ventral presents, nodding, and contact swimming. Photo by Mark Cotter.

Table 2.—Chronological description of socio-sexual behavior observed among a group of nine beluga whales on 24 April 2014 and associated figure references.

Time	Description of Observations	Affiliative and socio-sexual behavioral events observed[1]	Figure no.
13:20	Nine adult (white) beluga whales sighted in 3 distinct pairs exhibiting affiliative behavioral events; 3 other solo individuals were ~50 m away but were not seen to interact with any other whales.	CS, ES, C	2, 3[2]
13:22	Two animals seen swimming in separate silt trails ~10 body lengths apart.		2, 3
13:23	Pair 1 – one animal performed multiple rostro-genital contacts or "goosing" of the other animal.		3
13:24	Pair 2 - slowly rolled around each other in physical contact, created large plumes of silt and presented ventral sides.	C, VP	4
13:25	Pair 3 - contact swimming seen with necks and heads both cocked inwards facing each other, nodding and almost touching. One animal rotated onto its side, ventral facing towards the other beluga. Two pelvic thrusts observed, followed by returning to side-by-side contact swimming and head touching.	CS, Nd, VP, Th	5, 6, 7
13:26	Pair 1 observed engaging in similar pelvic thrusting by one animal to the other, and ventral-ventral contact followed by close-contact swimming with the thrusting animal maintaining contact with one pectoral fin.	Th, VVC, VS, VP, C, Rb	8
13:27–13:28	Pair 3 continued pelvic thrusting multiple times, followed by both animals diving straight down and out of sight.	Th, VP, VVC, VS	9
13:31	Observations ended.		

[1] See Table 1 for event definitions
[2] Only one pair is exhibited in these figures.

ly observed during the spring season at the same geographic location where water was unusually clear.

Further observations of this behavior are necessary to confirm if it is seasonally related or occurs in only certain areas of Cook Inlet. However, the exceptionally observed and photo-documented rarity of such behavior is important to both note and report for ecological management and conservation purposes.

Unlike other beluga populations in Alaska, the endangered CIBW stock is believed to be confined to the Cook Inlet estuary, representing a relatively small genetically and geographically isolated population (O'Corry-Crowe et al., 1997; Laidre et al., 2000) Accordingly, the CIBW population is potentially more susceptible to physical, ecological, and anthropogenic stresses (Moore et al., 2000; Norman et al., 2015). NMFS aerial survey results indicated nearly a 50% decline in the CIBW population between 1994 and 1998 (Hobbs et al., 2015b). This acute decline was attributed to unregulated hunting. However, even after the hunt virtually ceased, no appreciable increase in abundance has been documented (Hobbs et al., 2015b).

In 2008, the CIBW was listed as endangered under the U.S. Endangered Species Act, and a CIBW Conservation Plan was developed (NMFS, 2008), followed by identification of critical habitat in 2011 (NOAA, 2008). The Conservation Plan specifically identified the need to characterize CIBW life history traits and improve knowledge of mating systems (NMFS, 2008). Identifying temporal and spatial habitat-use patterns, as well as confirming the peak period of mating, are critical to ensure protection of potentially important behavioral regions and seasons sensitive to population recovery, further mitigating potential decline of this already depleted population.

Summary and Conclusion

Our observations represent a unique contribution lending insight into the little-known social-sexual behavior of free-swimming beluga whales, including temporal and geographical aspects. Documenting and understanding mating systems and related behavior is critical for effective management and conservation of this endangered population. Such information also begins to address critical data gaps for this species identified in the NMFS 2008 CIBW Conservation Plan (NMFS, 2008) and draft Recovery Plan (NMFS[7]), providing some insight on the natural history, mating behavior, seasonality, and potential behavioral-based habitat preference of this declining population.

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[7]NMFS. 2015. Draft recovery plan for Cook Inlet beluga whale (*Delphinapterus leucas*). U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Alaska Region. Off., Protected Resour. Div., Juneau, AK, 274 p.

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Annual Calf Indices for Beluga Whales, *Delphinapterus leucas*, in Cook Inlet, Alaska, 2006–12

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ABSTRACT—Beluga whales, Delphinapterus leucas, *in Cook Inlet, Alaska, form an isolated, depleted population that is now listed as endangered. Calving rates are an indicator of population health and the potential for recovery. Most births in Alaska beluga whale populations occur by late July; therefore, systematic aerial surveys were conducted in August covering primary habitat in upper Cook Inlet and compared to similar surveys conducted in June. Paired video cameras, one capturing the entire beluga group and the other magnified to detect smaller, darker whales, provided images used in laboratory analysis. Calves were found in 27 of 82 groups video-sampled in June and 22 of 54 groups in August. Calves were identified by their small size, skin color (darker than adults), behavior, and proximity to adults, using images captured in zoomed video. Proximity to an adult beluga (five categories) determined two calf indices, one represented young-of-the-year calves (Index 1) and the other all dependent calves up to about 3 years of age (Index 1–5). Biases associated with this method include: 1) surfacing frequency of calves, 2) verification of relative image size assumptions, and 3) the unknown fraction of mature females.*

In both June and August, the smallest calves were found in the proximity 1 category (i.e., calf touching adult). Indices suggest that most calves were born between June and August, with smaller calves (likely 0–2 months old) in all proximity categories in August. In June, the indices were similar across years with a 7-yr average for Index 1 of 1.2% (SD = 0.5%). August had significant variation. In August 2006, Index 1 was 12% suggesting that it was a good year for new calves. From 2007 to 2012, Index 1 in August ranged between 0.5 and 3.5% suggesting that these were poor calving years. June indices did not correspond to the previous August, therefore, video data from June 1995 to 2005 could not be used for a calf index. Knik Arm had the highest index values for both indices in June and August, with more than twice the values in the Susitna area, and indices were lowest in the Turnagain area.

The average per capita calving rate was 3.5% (SD = 4.3%) compared to a minimum estimate of mortality of 2% (SD = 1.2%; 2006–12) from carcass counts, suggesting the birth rate was probably at or below the replacement level. If adult females make up about 30% of the Cook Inlet population, then on average 12% gave birth each year which was one-third the maximum rate estimated for other Alaska beluga populations

Introduction

Alaska's Cook Inlet is home to a group of beluga whales, *Delphinapterus leucas*, which is genetically distinct and geographically isolated from beluga whale populations in western Alaska and the Arctic (O'Corry-Crowe et al., 1997; Laidre et al., 2000). After a period of unregulated Native subsistence hunting, the Cook Inlet beluga whale (CIBW) stock was determined to be depleted under the U.S. Marine Mammal Protection Act in 1999 (NOAA, 2000). In 2008, this distinct population segment (DPS) was listed as endangered under the U.S. Endangered Species Act (ESA) (NOAA, 2008).

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As of 2012, the CIBW population has failed to show any signs of recovery, with an abundance trend showing a continued decline (Hobbs et al., 2015). ESA Recovery Plans require criteria defining benchmarks for extinction risk as part of the recovery efforts (NMFS[1]). One indicator of recovery or decline in a population is change in calving rates. For example, a decline in calving rate would result in a shortage of replacements and an ensuing decline in population size.

In the Saint Lawrence estuary (SLE), Canada, belugas inhabit an environment similar to Cook Inlet. The SLE population has not shown appreciable recovery since the end of hunting in 1979 (DFO, 2012, 2014). Females give birth between June and August after a gestation period of a little over 14 months (Béland et al., 1990, 1992). Calves may nurse up to 2.5 yr (Brodie, 1971; Sergeant, 1973; Seaman and Burns, 1981) resulting in a 3-yr calving cycle.

In Cook Inlet, traditional knowledge from Native hunters indicated calving occurs from April through August (Huntington, 2000). Hunters described calving areas and timing: in the lower inlet along the northern side of Kachemak Bay in April and May; and in the northwestern portion of the upper inlet near the Beluga and Susitna rivers in May, and Chickaloon Bay and Turnagain Arm in summer (Huntington, 2000:138).

In the late 1970's, calves were not observed during mid-June aerial surveys (Shelden et al., 2015; Murray[2]).

[1]NMFS. 2015. Draft recovery plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Alaska Reg. Off., Protected Resour. Div., Juneau, 274 p.

[2]Murray, N. K. 1979. Belukha whales in lower Cook Inlet. U.S. Dep. Commer., NOAA, OCSEAP Annu. Rep. Princ. Invest. 1(1979):192-208 *In* D. Calkins and K. Pitcher (Princ. Invest.). Population assessment, ecology and trophic relationships of Steller sea lions in the Gulf of Alaska, Res. Unit 243, p. 144-208 (avail. at

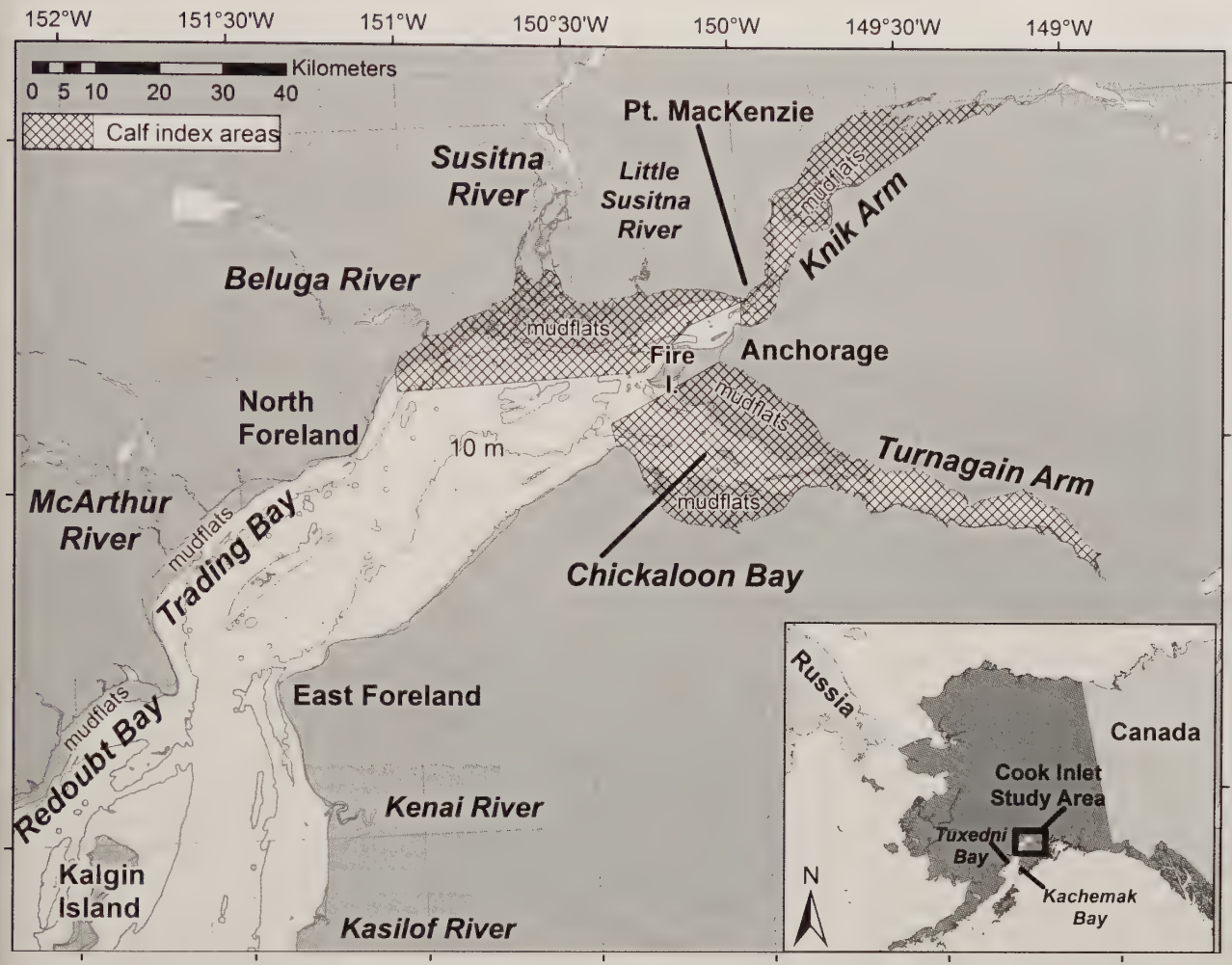


Figure 1.—Study area for the Cook Inlet, Alaska, calf index aerial surveys, August 2006–12. Three shaded regions: Susitna (from Beluga River to Pt. MacKenzie), Knik (Knik Arm), and Turnagain (including Chickaloon Bay and Turnagain Arm) denote where most beluga groups were observed during the study period.

By the mid-July surveys, Nancy Murray reported calves at Beluga River, in Trading and Redoubt bays, and in mid-inlet waters south of Fire Island (Shelden et al., 2015). She noted on one occasion:

> "There were several (8–10) very large white animals, and about 12 small grey animals about ¼–⅓ the length of the larger white 'females' they swam alongside. These small animals were very dark slate grey, darker than any juveniles I've seen so far. I can't help but think that these are recently born calves which have been born since the June 18th flight" (Shelden et al., 2015: Appendix 1).

Murray[2] also reported calves in the central inlet between Kalgin Island and Kasilof River in mid-August, and in Tuxedni Bay in mid-October (Fig. 1).

During aerial surveys conducted in upper Cook Inlet waters in the early 1980's, Calkins[3] noted:

> "No neonates were positively identified on any of these surveys due to the turbid water conditions. However, on both the May 17 and the June 4, 1982 surveys, very dark, small belukhas were sighted. These could have been newborn calves although this was not determined because newborn calves and yearlings differ in length by approximately 30 cm (John Burns, pers. comm.); determining 30 cm difference between animals from an aircraft at 100 to 200 m altitude and moving at an airspeed of approximately 80 kts with the belukhas in highly turbid water proved to be an impossible task" (p. 3).

http://www.arlis.org/docs/vol1/OCSEAP2/Annual/5721406/A1979%20V01.pdf and accessed 4 Mar. 2015).

[3]Calkins, D. G. 1984. Belukha whale. Vol. IX of Susitna hydroelectric project; final report; big game studies. Alaska Dep. Fish Game., Doc. 2328, 17 p. (avail. at http://www.arlis.org/docs/vol1/Susitna/23/APA2328.pdf and accessed 4 Mar. 2015).

Since the early 2000's, the entire CIBW population, with the exception of a few whales, has remained in or moved into upper inlet waters from the lower inlet by early June (Shelden et al., 2015). Based on the May calving time hunters identified for the Susitna area (Fig. 1), and the mid-July calf sightings during aerial surveys in the 1970's, we assumed most calves had been born by August. Thus, the location and timing of our calf study focused on upper inlet waters in August, but we also compared results to the early June surveys conducted each respective year.

A few small, dark belugas have been observed on occasion during the June surveys. On 10 June 2010, the NMFS aerial team (including three of the coauthors: KEWS, DJR, LVB) witnessed what appeared to be a birth along the unexposed mudflat edge between the Little Susitna River and Fire Island. An adult whale accompanied by two adults was observed rolling at the surface, there appeared to be blood in the water, then the whale, presumably the mother, lifted a small, dark calf to the surface on its back.

Young-of-the-year remain in close proximity to their mothers, and even at 1–2 months post-partum they are nearly always in contact with their mothers (Krasnova et al., 2006; Suydam, 2009). This proximity to an adult, and the size and color of these small whales (dark gray compared to the white adult), makes them more readily identifiable as calves. Given the difficulty of identifying calves in the turbid waters of the upper inlet, we developed a method using video recording of beluga groups that were counted during aerial passes. Here, we describe techniques used to create a calving rate index and discuss the implications for the conservation and recovery of the depleted and isolated CIBW population.

Methods

To develop a calf index for CIBWs, the NMFS National Marine Mammal Laboratory (NMML) conducted aerial surveys in August annually, beginning with a pilot study in August 2005 (Rugh et al.[4]; Shelden et al.[5,6,7,8,9], Sims et al.[10]). These surveys followed the same protocols used during the June abundance surveys (Rugh et al., 2000, 2005; Shelden et al., 2013). In this respect, the data sets would be comparable between June and August and would allow for a retrospective calf index analysis of video data collected during June surveys for the period 1995–2005. Data collection methods in August were largely proscribed by the methods used for the June survey and innovation focused on development of new analysis methods to assign age classes (calf, subadult, and adult) to the video images. The analyses were developed over a period of years and in some cases went through a series of trial and refinement steps before arriving at the methods presented here (Hobbs et al.[11], Sims et al.[12,13]).

Study Area

Cook Inlet is a long bay and estuary north of the Gulf of Alaska. Currently, the CIBW population inhabits three primary areas during the month of August, denoted as the following for the purposes of this study (Fig. 1):

"Susitna" which includes the northwestern portion of the upper inlet between Point MacKenzie and Beluga River;

"Knik" which is Knik Arm, north of Anchorage, the largest city in Alaska; and,

"Turnagain" which includes Turnagain Arm and Chickaloon Bay, in the northeast portion of upper Cook Inlet.

Data Collection

Aerial surveys were flown in twin-engine, high-wing aircraft at an altitude of 244 m (800 ft) and speed of 185 km/h (100 kn). The forward right and left observer positions had bubble windows to maximize the search area. The data recorder used a laptop computer[14] connected to a handheld portable Global Positioning System (GPS) to record survey effort and sighting data.

[4]Rugh, D. J., K. T. Goetz, C. L. Sims, and B. K. Smith. 2006. Aerial surveys of belugas in Cook Inlet, Alaska, August 2006. Unpubl. field rep., 9 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2006.pdf), accessed 19 July 2011).

[5]Shelden, K. E. W., K. T. Goetz, and J. A. Mocklin. 2007. Aerial surveys of belugas in Cook Inlet, Alaska, August 2007. Unpubl. field rep., 11 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2007.pdf), accessed 19 July 2011).

[6]Shelden K. E. W., K. T. Goetz, L. Vate Brattström, B. A. Mahoney, M. Migura-Krajzynski, and B. S. Stewart. 2008. Aerial surveys of belugas in Cook Inlet, Alaska, August 2008. Unpubl. field rep., 11 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/aug2008.pdf), accessed 19 July 2011).

[7]Shelden K. E. W., K. T. Goetz, L. Vate Brattström, and B. A. Mahoney. 2009. Aerial surveys of belugas in Cook Inlet, Alaska, August 2009. Unpubl. field rep., 11 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/august09.pdf), accessed 19 July 2011).

[8]Shelden K. E. W., L. Vate Brattström, and C. L. Sims. 2010. Aerial surveys of belugas in Cook Inlet, Alaska, August 2010. Unpubl. field rep., 12 p. (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/august2010.pdf), accessed 19 July 2011).

[9]Shelden K. E. W., L. Vate Brattström, and C. L. Sims. 2011. Aerial surveys of belugas in Cook Inlet, Alaska, August 2011. Unpubl. field rep., 10 p. (avail. at http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/survey/august2011.pdf), accessed 28 May 2015.

[10]Sims, C. L., L. Vate Brattström, and K. T. Goetz. 2012. Aerial surveys of belugas in Cook Inlet, Alaska, August 2012. Unpubl. field rep., 11 p. (avail. at http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/survey/august2012.pdf) accessed 28 May 2015.

[11]Hobbs, R., C. Sims, K. Shelden, L. Vate Brattström, and D. Rugh. 2012. Annual calf indices for beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, 2006-2010. AFSC Proc. Rep. 2012-05, 29 p.

[12]Sims, C. L, R. C. Hobbs, and D. J. Rugh. 2003. Developing a calving rate index for beluga in Cook Inlet, Alaska using aerial videography and photography. Abstr. (poster) in Fifteenth Biennial Conference on the Biology of Marine Mammals, Greensboro, N.C. 14-19 Dec. 2003.

[13]Sims, C. L., R. C. Hobbs, K. T. Goetz, and D. J. Rugh. 2007. Using advanced techniques to determine age categories of belugas. Abstr. presented at the First International Workshop on Beluga Whale Research, Husbandry and Management in Wild and Captive Environments, 9-11 Mar. 2007, Valencia, Spain.

[14]Starting in 2006, survey data were entered using a new software program specifically developed for the Cook Inlet beluga aerial survey by Niel Goetz and Kimberly Goetz, Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Natl. Mar. Mammal Lab., 7600 Sand Point Way NE., Seattle, WA 98115-6349.

Survey software routinely recorded time and location from the GPS every few seconds, as well as when sightings or comments were entered. Other data collected included percent cloud cover, sea state (Beaufort scale), glare (on the left and right sides), visibility (on the left and right sides), beluga group count data, and other marine mammal sightings. Because belugas in Cook Inlet tend to be found near shore during the summer months, aerial surveys included coastal tracklines within 1.4 km of the apparent waterline in addition to offshore transects. The survey also included searches up rivers until the water appeared to be too shallow for belugas (as indicated by Native Alaskan hunters who participated in past surveys).

The August survey design was similar to that of the June abundance surveys (Rugh et al., 2000, 2005; Shelden et al., 2013) with the exception that tracklines were not flown south of Kalgin Island. Since the early 2000's, almost all beluga sightings (systematic and opportunistic) have occurred in the upper inlet during the summer (June–August) (Shelden et al., 2015). During the period 2006–12, we compared beluga group distributions and raw counts collected each June (Shelden et al., 2013) to the respective August survey while underway, to ensure large portions of the population were not missed. After the field season, opportunistic sighting reports were reviewed to verify that no large groups of belugas were seen outside of the survey area (Shelden et al., 2015; Vate Brattström et al.[15]). Video data were collected during each respective June and August survey using the same camera system to facilitate within-year comparisons which would be used to determine when most young-of-the-year calves were born.

[15]Vate Brattström, L., C. Sims, R. Hobbs, and B. Mahoney. 2010. The Cook Inlet beluga whale opportunistic database: A summary of opportunistic sightings during the past 35 years. Poster pres. at Alaska Mar. Sci. Symp., Anchorage, AK, Jan. 2010 (avail. at: http://access.afsc.noaa.gov/pubs/posters/pdfs/pVate-Brattstrom01_cook-inlet-beluga-db.pdf and accessed 22 Jan. 2014).

Counting and Video Passes

When beluga groups were seen, each observer reported the sighting to the data recorder. As the aircraft passed abeam of the whale group, the observer(s) informed the recorder of the inclinometer angle and notable group behaviors but not group size. Whale group locations were marked via GPS with the survey program before the onset of the counting passes. Counts of each whale group were made by following an extended oval (racetrack pattern) around the group. Counting passes of the beluga groups were made on each pass down the long axis of the oval following procedures used during abundance surveys (Rugh et al., 2000, 2005; Shelden et al., 2013). Daily aerial counts of beluga groups were represented by medians of each observer's median counts on multiple passes (typically 4–8 passes) over each whale group.

Video Procedures

Paired, video cameras that were mounted side-by-side on a hand-held board were used to document beluga whale groups. One camera lens was set at wide angle to view the entire beluga group (referred to hereafter as "standard" video) and was used to assess the number of belugas in a group. The second camera lens was zoomed to approximately 10–15X magnification to enlarge a subsample of individual whales in the group (referred to hereafter as "zoomed" video). The zoomed video was used to examine color ratios of white adults relative to dark juveniles (Litzky, 2001; Sims et al.[12,13]) and to determine correction factors for missed animals (Hobbs et al., 2015).

Calf index surveys began in August 2005 with an experimental survey to test video camera resolution compared to still camera photography. A high-speed digital single-lens reflex (SLR) camera (Nikon D1X[16]) was used for the zoomed data collection, paired alongside a mini-digital video camera (Sony DVCAM, DSR-PDX10 Model L10A). Although clear images of calves were captured, the camera would pause after several frames to write to memory and was unable to fire fast enough (approximately 3 frames per second) to ensure adequate sampling. Consequently, the still camera was less than ideal because it could not reliably capture enough frames of a surfacing event to determine the midpoint of a whale's surfacing (i.e., the maximum image size as described below in the video analysis section).

In 2006, both the standard video camera and the zoomed still camera were replaced with high-definition (HD) video cameras (JVC GR-HD1, 1290 × 720 pixels) to collect both standard and zoomed video. While the resolution of the JVC HD video cameras (1290 × 720 pixels) was lower than the resolution of the Nikon still camera (3008 × 1960 pixels), the jump in resolution was an improvement over the Sony DVCAM video resolution (720 × 480 pixels).

A test of the system in May 2006 (Rugh et al.[17]) demonstrated that the continuous zoomed HD video gave a better sampling of beluga surfacings than the Nikon still camera. The HD video provided sufficient resolution for calf detection as well as more frames of each surfacing for image size comparisons. Therefore, the HD video was used for the zoomed sampling in 2006 and later, and data collected with the Nikon still camera during the 2005 survey were not used in subsequent analysis. In 2011, the JVC HD cameras were replaced with higher resolution (1920 × 1080 pixels) Sony HSR-NX5U HD video cameras.

Video Analysis

Post-survey, video recordings were digitally streamed into a computer, edited, and exported so that each count-

[16]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[17]Rugh, D. J., K. T. Goetz, and C. L. Sims. 2006. Aerial surveys of belugas in Cook Inlet, Alaska, May 2006. Unpubl. field rep., 8 p. (avail. at: http://www.fakr.noaa.gov/protectedresources/whales/beluga/survey/report0506.pdf), accessed 19 July 2011).

ing pass was saved as an individual video file. During the editing process, video passes were reviewed to ensure each video clip was sufficient quality for counting whales. Quality ratings were excellent, good, fair, poor, or unacceptable, as defined in Hobbs et al. (2000), based on factors that could affect the quality of the image such as camera focus or factors that affect the visibility of whales in the field of view such as presence or absence of whitecaps or glare. Only aerial passes with excellent or good ratings were used in the analysis.

After each video was assessed for quality and exported, the clip was analyzed using the "Beluga Dots" program, software designed specifically to analyze video of beluga groups collected during these surveys.[18] The Beluga Dots program, used on Macintosh computers, allowed an analyst to mark and number each individual whale image, track the individual whales across the screen, and use tools to measure whale image size and assign color. The computer program electronically recorded all relevant information (surfacing and diving time of each whale, size and color of individual whales, and total count of the group) to a database. The program allowed analysts to review the video frame by frame or in slow motion an unlimited number of times, compare time synchronized standard and zoomed video from the same pass over a group, and enter and edit data collected during the video review whenever necessary.

Each standard video sequence was examined by a primary analyst who cataloged individual whales, noted surfacing time (the first frame where a whale was visible), diving time (final frame where a whale was visible), measured whale images (pixel size), and noted color (bright white, dull white, light gray, medium gray, and dark gray using a color scale in the analysis program). Image size was measured at the midpoint of a surfacing (halfway between surfacing time and diving time) when the largest portion of the beluga was exposed above the muddy water. If the whale midpoint image was blurred due to motion of the camera, the analyst would search forward and backward frame by frame to find a clear image of equivalent size. Whales that surfaced prior to appearing on-screen or did not dive before going off-screen, and whose midpoint occurred near the edge of the screen, were not included in the analysis as the true midpoint may have occurred off-screen.

After the primary analyst completed the first review, a second analyst reviewed each video clip and corresponding data file to confirm the primary analyst's whale count and individual whales, searched for any missed whales, and completed second measurements of each whale image size and color. The computerized analysis of video allows for thorough, documented counting of groups compared to counting real time during the aerial survey. When possible, multiple video passes of the same group were sampled.

Once the analysis of a standard video pass was completed, if there was a usable zoomed video sequence for that pass, the zoomed video was synchronized to the standard video and analyzed. The two cameras were aligned such that the zoomed video frame was centered and contained within the standard video field of view. Using the time stamp and objects that appeared at the surface in both the standard and zoomed video, the analyst could estimate the relative magnification within a video frame. The zoomed video captured higher magnification images of the animals seen in the standard video and often included small, gray-colored beluga whales that were undetected in standard video due to size (much smaller than adults), dark color (blending with the muddy water), or surfacing behavior (only a small portion of the whale broke the water surface). The proportions of these missed beluga were used to correct the group counts for missed whales when estimating group sizes (Hobbs et al., 2000, 2015), and the calf index was then derived from whales found in the zoomed video using the images that met specific criteria presented below.

A feature in the Beluga Dots software program allowed the analysts to compare the synchronized zoomed and standard video clips frame by frame. The whale images in the zoomed video were cataloged and measured then compared to images in the standard video to determine if they were also found in the standard video. If a whale was also visible in the standard video, the midpoint, if available, was used to determine if the zoomed image was at the maximum size. Midpoints that occurred more than one second outside the boundaries of the zoomed frame were considered unmeasurable in the zoomed video. For smaller whales that were visible only in the zoomed video, the portion of the surfacing was reviewed and a maximum point was identified only if the whale was clearly visible at the surface. The exposed back was measured along the longitudinal axis (in pixels) and used for size comparisons between whales.

Identifying Calves, Subadults, and Adults

Whale images in zoomed video were initially identified as calves, subadults, adults, uncertain, or unusable, based on their color, size relative to large, white belugas, and behavior. The methods were largely objective but require experienced video analysts to apply. Zoomed video with inconsistent lighting or glare patches was not used, consequently, the color measurement was thought to closely correspond with the color of the beluga itself.

Typical surfacing behavior for adults, subadults, and calves older than one year was a slow roll, which appeared in the video as exposure of the back of the head followed by the dorsal surface with the caudal peduncle submerging last (belugas rarely exposed flukes). The maximum longitudinal length exposed above the muddy water was between the blow-

[18]Starting in 2004, video data were analyzed using a new software program, "Beluga Dots", specifically developed for the Cook Inlet beluga aerial survey by Steven Hentel, 6170 NE 187th Pl., Kenmore, WA 98028.

hole and the caudal peduncle. These surfacings took between 2 and 5 sec. Less typical behavior was the headlift in which the beluga exposed just the head and blowhole to breath and submerged without exposing the back. Calves showed more varied behavior and included surfacing behavior in which the calf was partially supported or lifted by an adult.

Relative size was calculated as the ratio of the pixel size of a gray beluga to the average pixel size for white adults showing typical surfacing behavior in a counting pass. This was then averaged for each survey period (year) and study area (Susitna, Knik, and Turnagain). The turbid water in Cook Inlet precluded measuring full body lengths of whales, so we assumed that the maximum size of an image was proportional to the standard length of the whale. From Suydam (2009), we note that the size of a 3-yr old female (i.e., the point at which most calves have weaned (Matthews and Ferguson, 2015)) is about 60% of the size of an average adult female and 50% of the size of an average adult male. In most cases, calf sizes could be compared to only one or two adults in the same pass and same frame. With uncertainty as to the sex of the adult, and other issues such as camera angle and movement, as well as variation in the surfacing behavior of calves, relative size was used as a guideline only. We used 60% of the relative size as the breakpoint between smaller gray individuals that were more likely to be a calf and larger gray individuals that were more likely to be a subadult.

All large, bright-white and dull-white individuals were classed as adult whales and considered usable if their maximum size could be measured within the zoomed video. Where large adult whales were easily identified in the zoomed video, smaller gray whales were harder to differentiate from the water and by behavior. An analyst followed a list of four criteria to first determine if a questionable whale was in fact a whale and perhaps a calf.

First, did the movement of the questionable whale in the video appear to be surfacing or diving? This movement was detected by a change in the size of the portion of the whale that was visible above the water. Second, was the part of the whale that was visible shaped like that of other whales (oblong or tear drop shaped) depending on what portion of the surfacing was visible? Third, did the amount of time the whale was visible on screen allow enough time to detect movement and shape of the whale? Finally, did enough of the surfacing of a small, gray beluga occur within the zoomed video to allow a size measurement so that the analyst could compare the relative size of the whale to adults in the pass?

Small, dark to medium gray individuals showing behavior typical of calves (breaking the surface then quickly disappearing) were classed as calves. Intermediate sized, medium or light gray individuals showing behavior more similar to adults (slow roll surfacing) were classed as subadults. Adults showing behavior other than a slow roll were considered unusable. Whale images of gray belugas that could not easily be put into an age class were marked as uncertain. These were then reviewed by both analysts again and additional analysts were consulted. If the images remained uncertain, usually because they appeared for too short a time, they were considered unusable.

Calf Proximity and Selection of Images for Calf Index

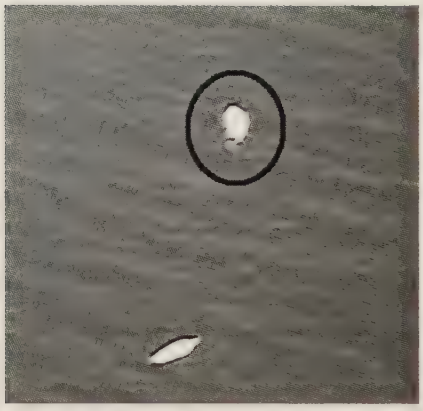
Whales identified as calves by their behavior and darker coloration were then categorized by their proximity to an adult whale based on distance in body lengths to the nearest adult in the field of view of the zoomed video. Because the entire body of a beluga was not visible, given the turbid waters of the upper inlet, a "body length" was an approximation based on the average adult image size (i.e., amount of an adult's dorsal surface that was visible above the water).

Krasnova et al. (2006) examined the spatial relationship between beluga calves and their mothers within the first 2 months post-partum. They found the most common positions during this developmental period were near the mother's flukes and at her side after comparing 11 behavioral elements. They used three categories for calf proximity: 1) "near the cow" which was within 1.5 m of the mother, 2) "at a distance from the cow" which was 1.5 to 5 m from the mother, and 3) more than 5 m away. Given the turbid conditions in Cook Inlet, we modified these categories into five proximity codes (1–5) as follows (Fig. 2):

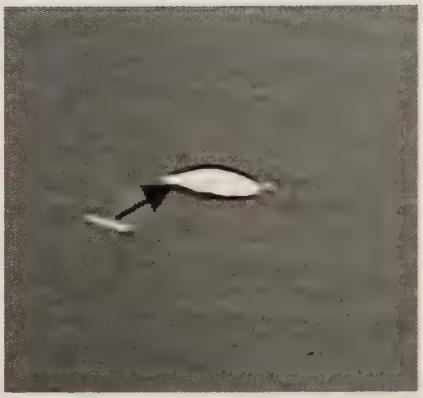
1) Calf touching an adult whale,
2) Calf within one body length of an adult whale,
3) Calf 2 or 3 body lengths from an adult whale,
4) Calf > 3 body lengths from an adult whale, and
5) Calf alone in field of view.

Due to water opacity, it is possible that an attendant adult was submerged, and therefore, undetectable in the muddy water. Krasnova et al. (2006) observed that very young calves may surface with the support of a submerged (thus invisible in Cook Inlet) mother, and therefore would appear to be alone (proximity 5) or if another adult was nearby to fall into proximity codes 2, 3, or 4. In addition, proximity codes 2, 3, and 4 could be affected by group behavior and density. The likelihood that random adult whales will happen to be near young whales would be expected to increase when groups are compact and milling than when whales are dispersed and travelling. In this respect, the proximity 1 sample may not contain all of the young-of-the-year calves that were recorded.

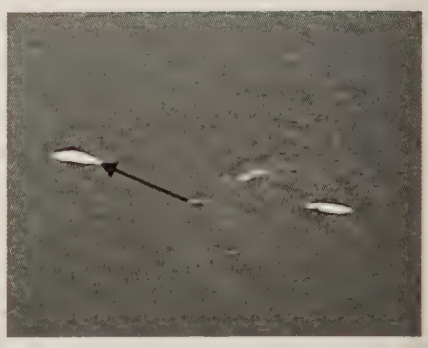
The narrow field of view for the zoomed video means a point on the water passes through the zoomed video in about 1–2 seconds. The surfacing time for calves is one-half to one-third that of the accompanying adult (which would be visible at the surface for 2–5 seconds). To avoid bias in the sampling from this longer surfacing interval, we further subsampled the measurable adults and only used adult images that were near their maximum size (i.e., measurable in the



Code 1. Calf touching an adult whale.

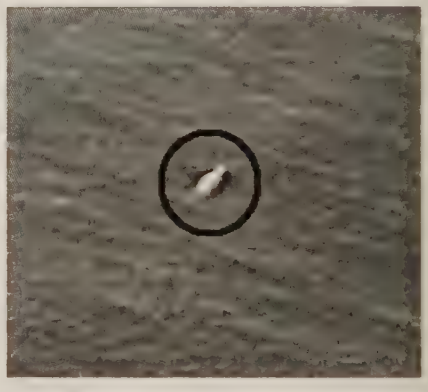


Code 2. Calf within one body length of an adult whale.



Code 3. Calf 2 or 3 body lengths from an adult whale.

Code 4. Calf > 3 body lengths from an adult whale.



Code 5. Calf alone in field of view.

Figure 2.—Beluga whale still images captured from video showing codes used to estimate proximity (Code 1–5) of calves to nearest adult.

zoomed video). To ensure a consistent sample, the following criteria were applied to select whales to include in the calf index analysis:

1) Adult whales in both the standard and zoomed video were used if the image in the zoomed video was within 20 or fewer frames (i.e., +/- 0.66 sec) from the estimated midpoint of their surfacing in the standard video. This ensured that the size measured for the adult was near its maximum size.
2) All whales that were found in the zoomed video that met the size (smaller relative to white adult whale) and color (medium to dark gray) criteria for calves and subadults and that appeared to be near the midpoint of surfacing.

Surfacing intervals for large adult belugas could be determined from the standard video but many calves and subadults were only visible in the zoomed video. For these small whales, 3–5 frames was usually adequate for the analysts to determine if the largest portion of the calf or subadult was visible for measurement. Therefore if a small, gray beluga was not visible for enough of a surfacing to confirm it as a calf or subadult, it was not used in the analysis.

By only using zoomed video images of whales that were near the midpoint of surfacing and, therefore, close to their maximum size at the water's surface, we removed the bias resulting from longer surfacing times of large adults and ensured that the measurements were consistent in representing the relative size of both large and small animals.

Calculation of the Calf Index

The probability that a surfacing beluga was a calf was estimated for each

year (2006–12), and for each geographic area (Susitna, Knik, and Turnagain) with all years combined. The probabilities were estimated using logistic regression in a generalized linear model (glm) (McCullagh and Nelder, 1989). The glm routine in the software package R was used to run the calculations. Each individual whale was treated as a sample drawn at random from the population with a sample weighting of the estimated group size divided by the number of samples from the group. This strategy prevented a single heavily sampled group from dominating the analysis.

Each sample was scored as a "1" if it was a calf and a "0" if it was not a calf. The logistic regression estimated a probability that a surfacing animal was a calf, $p(x)$, as

$$p(x) = \frac{e^{B(x)}}{1+e^{B(x)}},$$

where $B(x)$ was a normally distributed parameter with standard error, SE($B(x)$), estimated iteratively during the logistic regression, and x was either year or area. A 95% confidence interval for $B(x)$ was $B(x) \pm 1.96\text{SE}(B(x))$, which was transformed to an interval for $p(x)$ as

$$\frac{e^{B(x)-1.96\text{SE}(B(x))}}{1+e^{B(x)-1.96\text{SE}(B(x))}},$$

$$\frac{e^{B(x)+1.96\text{SE}(B(x))}}{1+e^{B(x)+1.96\text{SE}(B(x))}}.$$

In cases where the number of calves was zero, logistic regression cannot estimate the probability. Instead, we used the empirical logistic transform (Cox and Snell, 1989) to estimate the probability and an upper bound, so that

$$B(x) = ln\left(\frac{1/2}{m+1/2}\right) \text{and}$$

$$\text{SE}(B(x)) = \sqrt{\frac{m+2}{m}},$$

where m is the number of non-calves (subadults and adults) found, and ln is the natural logarithm. In this case, we calculated an upper bound using a one-sided 95% interval because the lower bound was clearly zero:

$$\frac{e^{B(x)-1.65\text{SE}(B(x))}}{1+e^{B(x)-1.65\text{SE}(B(x))}}.$$

The resulting estimate was the probability that an animal drawn at random from the population in a given year or area was a calf. This became the calf index for that survey period or area. Indices were developed to assess the relative number of calves in the population. Using the proximity data and the interpretation of age groups, we developed two indices:

1) Index 1. This index included only proximity 1 calves assumed to represent primarily young-of-the-year.
2) Index 1–5. This index included all proximity codes as a proxy for all dependent calves.

We can estimate a per capita birthrate, $q(x)$, in other words the probability that an individual in the population will have a calf in a year as

$$q(x) = p(x)/(1-p(x)).$$

It was not possible to distinguish males and females during our surveys; consequently, the calf indices were a measure of population level relative to reproductive success from year to year but not an actual measure of the reproductive success of mature females. At the population level, the number of births per capita can be compared to the number of mortalities per capita to estimate the growth rate. A crude estimate of mortalities per capita was calculated using the number of stranded carcasses found annually in Cook Inlet (NMFS[1]) divided by the population abundance estimate for that year (Hobbs et al., 2015).

To convert the index to an annual calving rate for adult females, we would need to know the number of adult females in the population. Currently, this information is not available for the Cook Inlet population. We instead present a scenario assuming that adult females make up about 30% of the population.

Results and Discussion

Aerial Surveys

Abundance surveys and calf index surveys were conducted each June and August from 2006 through 2012. Beluga whale groups were observed primarily in the Susitna area, Knik Arm, and Turnagain Arm (Fig. 3). The daily median counts in August (collected over 1–3 days) compared favorably to the range of daily median counts obtained during the June surveys (collected over 4–6 days: see Shelden et al. (2013)). Based on these results, and the lack of reports from other sources (Shelden et al., 2015), it was unlikely that any large groups of whales were missed during the August surveys (Fig. 4).

Video Analysis

Multiple surveys of the upper inlet were conducted in June and August, with beluga whale groups being resampled each day; therefore, totals represent the number of groups with usable samples rather than total number of groups in the inlet. Calves were found in 27 of the 82 groups video-sampled in June (195 counting passes) and 22 of the 54 groups video-sampled during the August surveys (165 counting passes). Only two calves, one from each month, were not included in the proximity analysis because a relative size could not be determined due to lack of usable adult images in the zoomed video pass. In most cases, calves and subadults were classified using coloration, behavior, and relative size, with all three in agreement. In 21 cases (June: 13; August: 8) where relative image size was greater than 60% of adult size, further review resulted in reclassification as subadult. In 23 cases (June: 16, August: 7), with relative image size less than 60% of adult size, further review resulted in reclassification as calves and assigning a proximity code. For June, 966 images were used in the calf index analysis, comprised of 48 calves, 74 subadults, and 844 adults (Table 1). August had 1,004 useable images which included 64 calves, 36 subadults, and 904 adults

Figure 3.—Survey effort and beluga whale group locations in Cook Inlet, Alaska, documented during annual abundance (June) and calf index (August) aerial surveys, 2006–12. The white circles include initial sampling and resampling locations of beluga groups over multiple survey days.

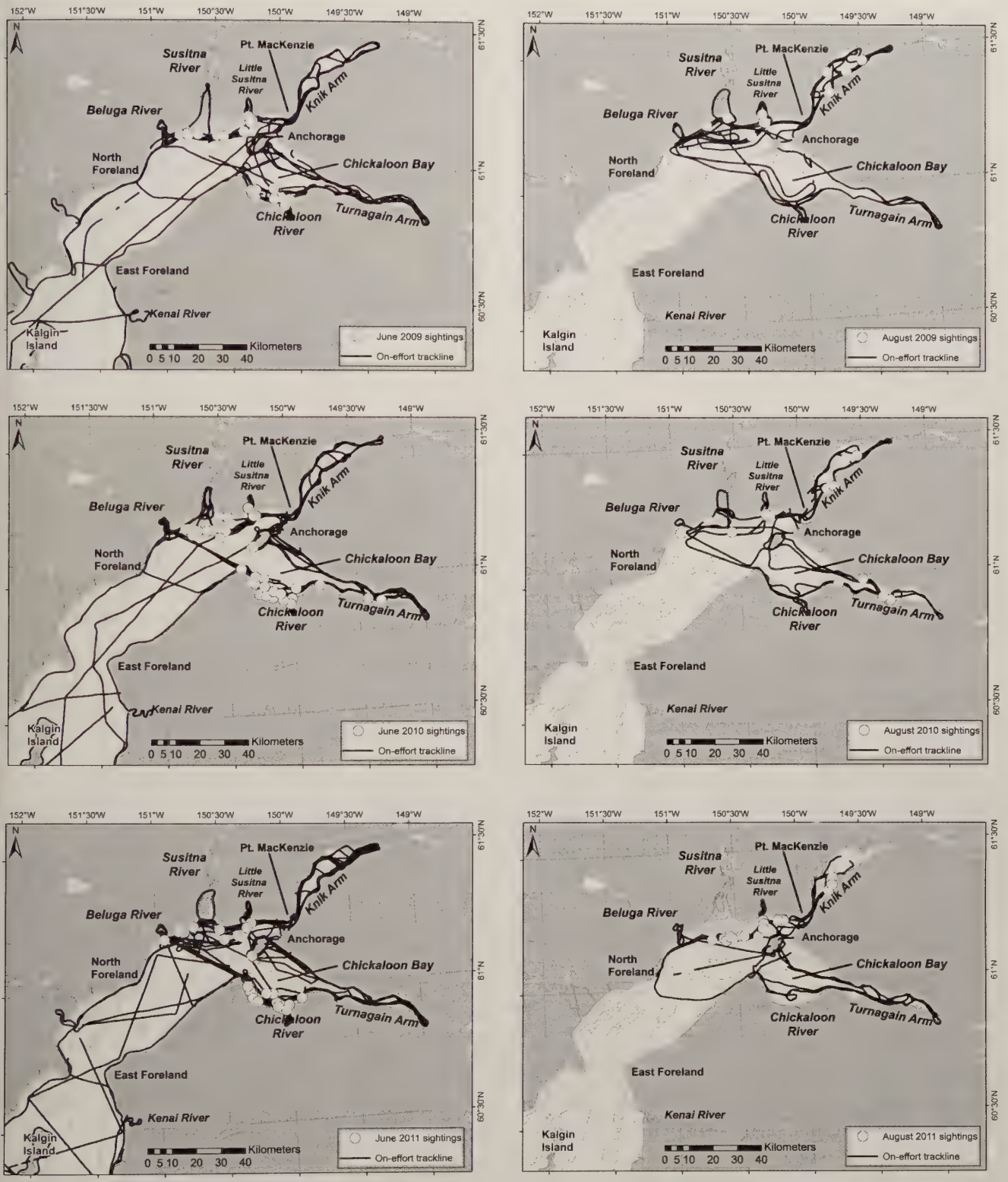


Figure 3.—*Continued*

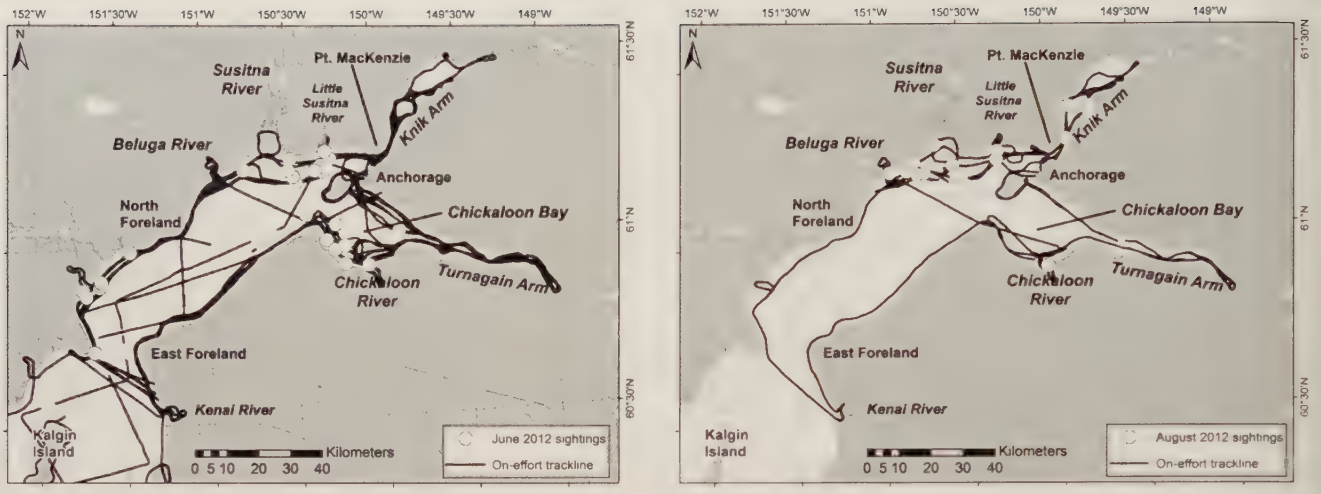


Figure 3.—*Continued*

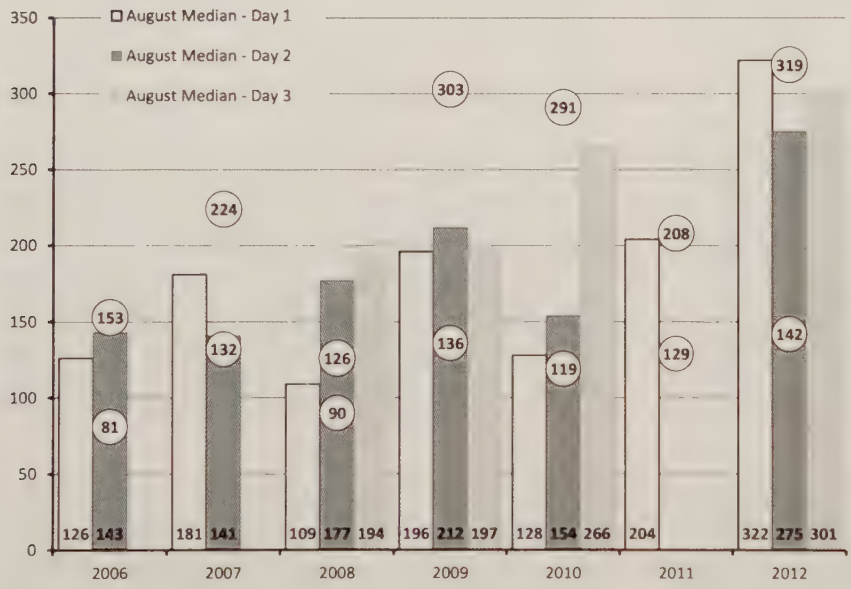


Figure 4.—Beluga whale daily median count totals for each survey day in August (2006–12) compared to the range of median counts obtained each respective June (circles) in Cook Inlet, Alaska.

(Table 2). Similar overall numbers of adults were found in zoomed video in both months, but more subadults were detected in June while more calves were detected in August.

The average relative size of apparent calves within each proximity category was estimated for June and August for each year and overall (Fig. 5). The June calves (Fig. 5a) tended to be relatively larger overall compared to those observed in August (Fig. 5b). This is consistent with our assumption that most calves are not born until later in the summer. The calves in the June sample would be 10 to 12 months old while the calves in August would be zero to 2 months old. In August, this difference is particularly evident in the proximity 1 category (i.e., calf touching adult) which represented 40% of the calf sample (compared to 25% of the June calf sample) which is consistent with observations by Krasnova et al. (2006) during which calves younger than 2 months were nearly always in contact with their mother.

For both months, the proximity 1 category produced the smallest (i.e. youngest) calves, while the other categories (excluding August proximity 5) included larger (older) calves. These results are consistent with the analysis in Suydam (2009) which showed that animals estimated to be 1 year old or older (based on size) spend less time in close proximity to an adult than smaller calves (<1 year old). The August proximity 5 calves (alone in field of view) may also include young-of-the-year based on relative size. Young-of-the-year calves are known to surface more frequently than the accompanying adult (Krasnova et al., 2006; Suydam, 2009), and given the turbid waters of Cook Inlet, the mother was likely present but submerged.

Beluga groups were found in greater numbers in the Susitna area in both June and August (Tables 1, 2; Fig. 3). This was not surprising as the Susitna area has always been an area of high occupancy even as this population has declined in numbers (Rugh et al., 2010; Shelden et al., 2015). Calves were smaller in August than June

Table 1.—Video passes reviewed for the presence of beluga whale calves in Cook Inlet, Alaska, in June 2006–12. Belugas were classified by color: adults (bright white to dull white), subadults (light gray), and calves (medium to dark gray), relative size, and surfacing behavior. Proximity codes are defined as 1) Calf touching an adult whale; 2) Calf within one body length of an adult whale; 3) Calf 2 or 3 body lengths from an adult whale; 4) Calf >3 body lengths from an adult whale; and 5) Calf alone in field of view. For the Index 1 and Index 1–5 analyses, each whale was treated as a sample drawn at random from the population with a sample weighting of the estimated group size divided by the number of samples from the group.

				Proximity codes								
Date	Area	Group ID	Passes sampled	1	2	3	4	5	Total calves	Total subadults	Total adults	Corrected group size
7 Jun 06	Turnagain	1	1								1	17
7 Jun 06	Turnagain	2	1								1	22
7 Jun 06	Susitna	4	1								1	26
8 Jun 06	Susitna	3	2							1	9	43
8 Jun 06	Susitna	6	2								2	13
11 Jun 06	Turnagain	1	1								2	7
11 Jun 06	Susitna	5	1								2	8
11 Jun 06	Susitna	6	2							1	5	181
11 Jun 06	Knik	7	1								1	15
12 Jun 06	Susitna	1	1		1				1		6	188
12 Jun 06	Turnagain	2	2							1	5	36
12 Jun 06	Turnagain	4	1								3	50
14 Jun 06	Turnagain	2	1								2	21
14 Jun 06	Turnagain	5	3								5	53
14 Jun 06	Susitna	7	3					1	1	4	18	163
14 Jun 06	Susitna	8	1	1					1		2	43
14 Jun 06	Susitna	9	2								2	31
15 Jun 06	Turnagain	2	1								1	15
15 Jun 06	Susitna	3	2								4	33
15 Jun 06	Susitna	4	1								4	51
15 Jun 06	Susitna	5	3								4	74
9 Jun 07	Knik	2	5		1			2	3	2	7	35
9 Jun 07	Turnagain	6	1								1	24
9 Jun 07	Turnagain	10	1								1	63
10 Jun 07	Susitna	2	3	1				1	2	3	9	84
10 Jun 07	Susitna	4	2								2	9
10 Jun 07	Susitna	5	2								1	54
10 Jun 07	Turnagain	6	3								6	1
10 Jun 07	Knik	7	2			1			1		3	31
10 Jun 07	Turnagain	10	2							1	3	21
10 Jun 07	Turnagain	11	3								9	42
11 Jun 07	Turnagain	4	6								7	35
11 Jun 07	Susitna	5	6			3		1	4	1	15	54
11 Jun 07	Susitna	6	5	1			1		2	1	66	223
11 Jun 07	Knik	7	1			1	1		2	1	3	40
14 Jun 07	Susitna	5	2								4	57
14 Jun 07	Susitna	6	3		1				1	2	26	177
14 Jun 07	Susitna	7	3								8	48
14 Jun 07	Susitna	8	3	1					1		6	39
15 Jun 07	Turnagain	2	1								1	9
15 Jun 07	Turnagain	3	3		1				1	2	3	5
15 Jun 07	Turnagain	4	2							1	2	15
15 Jun 07	Susitna	5	3							2	20	178
15 Jun 07	Susitna	6	1								1	17
4 Jun 08	Susitna	1	4			2	2		4	15	47	383
5 Jun 08	Turnagain	1	4				1		1	4	13	40
5 Jun 08	Susitna	2	4				1		1	2	7	77
6 Jun 08	Susitna	3	1							1	1	387
7 Jun 08	Turnagain	1	2							3	4	50
7 Jun 08	Susitna	2	2	1		1			2	8	17	313
12 Jun 08	Susitna	1	4	2					2	1	20	220
12 Jun 08	Susitna	2	5					1	1		10	64
2 Jun 09	Susitna	1	5	1		2			3	6	39	183
2 Jun 09	Susitna	2	5							3	19	90
3 Jun 09	Susitna	1	7					1	1		72	248
3 Jun 09	Turnagain	2	1								1	19
3 Jun 09	Turnagain	3	3								3	30
4 Jun 09	Susitna	1	4							5	13	87
4 Jun 09	Susitna	2	4				2		2	3	23	146
4 Jun 09	Turnagain	4	1								1	39
5 Jun 09	Turnagain	1	1								2	30
5 Jun 09	Turnagain	2	1								1	11
5 Jun 09	Susitna	4	5	2					2		29	181
1 Jun 10	Turnagain	3	2					1	1		4	51
2 Jun 10	Turnagain	1	2								7	126
2 Jun 10	Susitna	2	4	1					1		49	200
8 Jun 10	Turnagain	2	1								1	32
8 Jun 10	Susitna	3	1								1	74
8 Jun 10	Susitna	4	2								6	171
8 Jun 10	Susitna	5	1								2	69
10 Jun 10	Turnagain	2	1								1	3
10 Jun 10	Susitna	10	4								37	233
1 Jun 11	Susitna	3	2		1				1		23	271
2 Jun 11	Turnagain	1	1								5	22
2 Jun 11	Susitna	3	2		2	1			3		21	155
3 Jun 11	Turnagain	1b	2								7	77
5 Jun 11	Susitna	3	3								12	295
8 Jun 11	Turnagain	1	1								1	6
4 Jun 12	Trading Bay	2	1								5	17
4 Jun 12	Susitna	3	1								10	128
4 Jun 12	Susitna	4	1								4	173
5 Jun 12	Susitna	3	4	1	1			1	3		42	263
Totals			195	12	8	11	8	9	48	74	844	

Table 2.—Video passes reviewed for the presence of beluga whale calves in Cook Inlet, Alaska, in August 2006–12. Belugas were classified by color: adults (bright white to dull white), subadults (light gray), and calves (medium to dark gray), relative size, and surfacing behavior. Proximity codes are defined as: 1) Calf touching an adult whale; 2) Calf within one body length of an adult whale; 3) Calf 2 or 3 body lengths from an adult whale; 4) Calf >3 body lengths from an adult whale; and 5) Calf alone in field of view. For the Index 1 and Index 1–5 analyses, each whale was treated as a sample drawn at random from the population with a sample weighting of the estimated group size divided by the number of samples from the group.

				Proximity codes								
Date	Area	Group ID	Passes sampled	1	2	3	4	5	Total calves	Total subadults	Total adults	Corrected group size
16 Aug 06	Knik	1	2								1	16
16 Aug 06	Susitna	4	3	1		1		1	3	2	27	159
17 Aug 06	Turnagain	1	2							1	2	9
17 Aug 06	Susitna	5	3							4	3	61
17 Aug 06	Knik	6	2	1					1		5	127
17 Aug 06	Knik	8	1	1					1		1	44
1 Aug 07	Susitna	2	3	1					1		9	56
1 Aug 07	Susitna	4	3								20	71
1 Aug 07	Susitna	5	4	1					1		55	209
1 Aug 07	Susitna	6	1								12	143
2 Aug 07	Susitna	3	4	1	1		1		3	1	23	116
2 Aug 07	Susitna	4	5	2	1	2	6		11		26	153
12 Aug 08	Turnagain	1	3								4	80
12 Aug 08	Susitna	2	2					1	1		4	87
12 Aug 08	Knik	4	1								1	43
13 Aug 08	Turnagain	1	3								9	47
13 Aug 08	Susitna	2	4	4	5	1	2		12	3	41	143
13 Aug 08	Susitna	3	2							1	3	58
13 Aug 08	Knik	4	2								15	121
14 Aug 08	Turnagain	1	5			1			1		31	76
11 Aug 09	Susitna	1	5	1		1		1	3	3	53	206
11 Aug 09	Susitna	2	4								49	263
11 Aug 09	Knik	3	3								5	71
12 Aug 09	Susitna	1	3		1		1	1	3		18	205
12 Aug 09	Knik	2	4				1		1	6	11	100
13 Aug 09	Knik	1	4								7	47
13 Aug 09	Susitna	2	6	1			1		2	1	21	109
13 Aug 09	Susitna	3	3							1	8	20
13 Aug 09	Susitna	4	6	2	2	1	1	2	8	5	48	158
17 Aug 10	Turnagain	1	1								4	121
17 Aug 10	Susitna	6	2							1	4	76
18 Aug 10	Knik	1	2							2	2	206
18 Aug 10	Susitna	2	1								1	263
18 Aug 10	Turnagain	4	3								4	71
18 Aug 10	Turnagain	5	2								7	205
19 Aug 10	Knik	1	5							1	17	100
19 Aug 10	Susitna	2	7			1			1	2	29	47
19 Aug 10	Susitna	3	2								6	109
19 Aug 10	Turnagain	4	1								4	20
19 Aug 10	Turnagain	5	2								5	158
10 Aug 11	Knik	1	2								7	42
10 Aug 11	Susitna	2	5	1					1		37	128
10 Aug 11	Susitna	3	3	3					3		18	93
10 Aug 11	Susitna	4	4								12	55
11 Aug 11	Susitna	2	4								19	60
11 Aug 11	Susitna	3	5	1	1				2		48	163
11 Aug 11	Susitna	4	3	2					2		47	212
11 Aug 11	Knik	6	3								16	75
7 Aug 12	Susitna	1	2							1	20	231
7 Aug 12	Susitna	2	3							1	8	63
8 Aug 12	Turnagain	1	2								4	34
8 Aug 12	Susitna	2	4	1		1			2		37	186
9 Aug 12	Susitna	2	3	1					1		35	382
9 Aug 12	Knik	4	1								1	19
Totals			165	25	11	9	13	6	64	36	904	

within this area (Fig. 6). Similar to the annual averages, the proximity 1 category included the youngest calves while the other categories (excluding August proximity 5) were represented by older calves.

After 2007, belugas were no longer found in Knik Arm in June (Table 1; Fig. 3) but continued to be present in this area in August in all years but 2007 (Table 2; Fig. 3). Relative sizes of calves within this area were similar in June and August with most being smaller and thus likely young-of-the-year (Fig. 6). This suggests the Knik area may be an important nursery area. We do not know why belugas were no longer present in Knik Arm during the June survey period.

The Turnagain area has been consistently occupied in June, but whales were not present in 2009 and 2011 in August (Fig. 3). Few calves were found in the Turnagain area and almost all relative sizes were much larger than those in Knik Arm suggesting that these calves were older than a yearling in both June and August (Fig. 6).

Calf Indices

We used proximity 1 images as a proxy for young-of-the-year calves for Index 1. Proximity 1 calves were

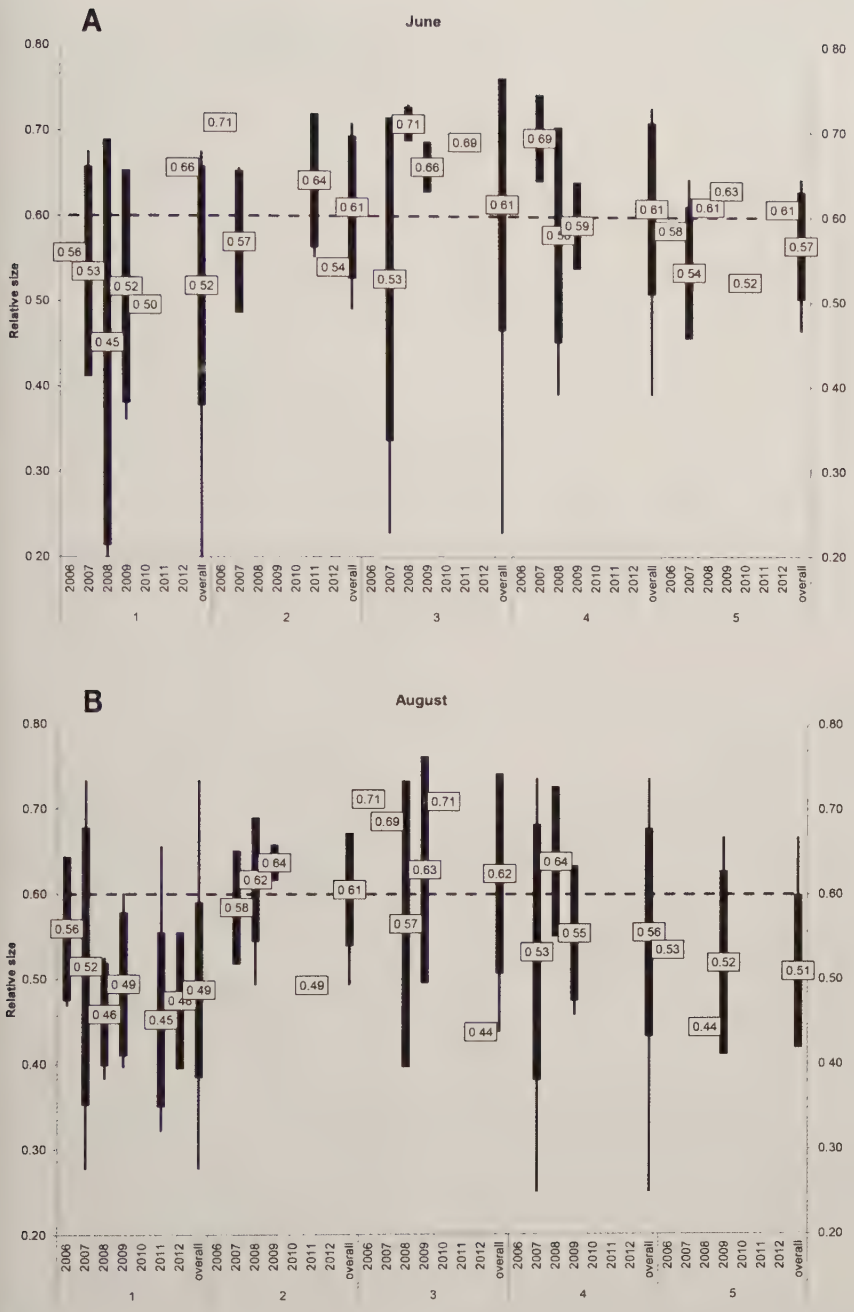


Figure 5.—Relative size for each calf proximity code per year and overall based on beluga whale video data collected during aerial surveys of Cook Inlet, Alaska, in June and August (2006–12). Bars indicate minimum and maximum ratio of calf to average adult size for the average ratio (in white box) with larger box representing +/- 1 standard deviation. Proximity codes are defined as 1) Calf touching an adult whale; 2) Calf within one body length of an adult whale; 3) Calf 2 or 3 body lengths from an adult whale; 4) Calf >3 body lengths from an adult whale; and 5) Calf alone in field of view. Estimated calf size was calculated by dividing calf pixel size by the average pixel size for all adult whales in the same counting pass. The 60% guideline (dashed line) represents maximum size of an unweaned calf.

not detected in the August 2010 or June 2011 video sample. Therefore, the probability that an animal drawn at random from the population would be a calf for those samples was estimated from the sample of adults and subadults using the empirical logistic transform. Index 1–5 included all dependent calves. Taken together, the two indices are nested, with Index 1–5 encompassing all of the young calves in Index 1.

In June, the indices were similar across years with Index 1 calves representing 0.4% to 1.5% of the population and Index 1–5 calves between 1.5% and 5.7% (Fig. 7a). The 7-yr (2006–12) average for Index 1 in June was about 1.2% (SD = 0.5%). The consistent low numbers for Index 1 suggest that the young-of-the-year calves, which by June would be 10–12 months old, no longer maintained close contact with the mother and instead behaved more like yearlings and older calves.

August was significantly different from June (Fig. 7b). In August 2006, young-of-the-year calves made up 12% of the population (Index 1) and both indices were fairly close, suggesting that it was a relatively good year for new calves (Fig. 7b). This large percentage of calves in 2006 would be encouraging for the health of the population and could be a highly sustainable level if it occurred in all years. The 7-yr (2006–12) average was 3.3% (SD = 3.8%). However, rates from 2007 to 2012 were between 0.5% and 3.5%, with a 6-yr average of 1.9%. With the inclusion of the large number of calves from the 2006 season, the probability of occurrence of Index 1–5 does not decline as quickly as Index 1 (Fig. 7b). Instead the decline occurred over 4 yr suggesting that Index 1–5 included calves up to 3 years of age.

Comparing June and August, we would expect both Index 1 and 1–5 for June 2007 to reflect the large number of young-of-the-year calves in August 2006. While Index 1–5 in June 2007 is the largest for the time series at about 6% of the population (Fig. 7a), no large increases or declines occurred

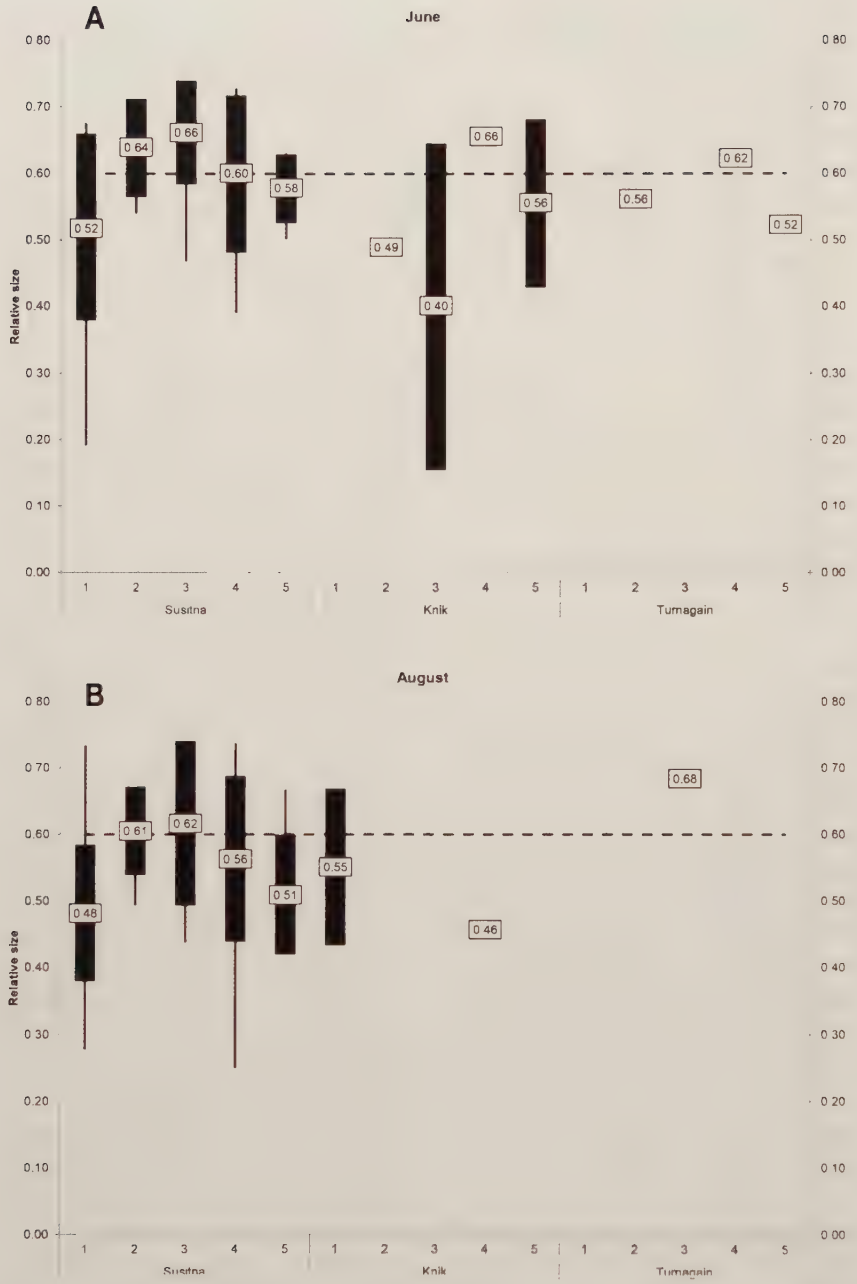


Figure 6.—Relative size for each calf proximity code per area (Susitna, Knik, and Turnagain) based on beluga whale video data collected during aerial surveys of Cook Inlet, Alaska, in June and August (2006–12). Bars indicate minimum and maximum ratio of calf to average adult size for the average ratio (in white box) with larger box representing +/- 1 standard deviation. Proximity codes are defined as 1) Calf touching an adult whale; 2) Calf within one body length of an adult whale; 3) Calf 2 or 3 body lengths from an adult whale; 4) Calf >3 body lengths from an adult whale; and 5) Calf alone in field of view. Estimated calf size was calculated by dividing calf pixel size by the average pixel size for all adult whales in the same counting pass. The 60% guideline (dashed line) represents maximum size of an unweaned calf. Note: belugas were not found in the Knik area in June after 2007, but were found there in August in all years but 2007. Belugas were not found in the Turnagain area in August in 2009 and 2011. Not shown: belugas in Trading Bay in June of 2012 (the sample of 5 whale images did not include calves or subadults).

in subsequent years as occurred in August. Also, the low percentage in August 2010 was not reflected in either of the June 2011 indices. Therefore, a retrospective analysis of video data from earlier June surveys (1995–2005) would not be useful for estimating a calf index given this lack of correspondence between August and the following June.

With its 95% confidence interval, Index 1 demonstrates that the sampling effort has been sufficient to show a difference between a good calving year (2006) and poor years (2007–12) (Fig. 7b). Although Index 1–5 shows significant differences between years, it is less certain what fraction of young animals this index represents. For example, when whale groups are very dense, calves and young juveniles are more likely to appear in the same video frame with an unassociated adult by chance.

Examining the indices as a function of area within Cook Inlet, it appears that Knik Arm is the preferred location for young-of-the-year calves in both June and August, with more than twice the likelihood that an animal is a young-of-the-year calf in Knik area than in the Susitna area, and an even lower probability of finding a calf in the Turnagain area (Fig. 8).

The probability of finding older calves was far greater in Knik Arm in June than in the other areas (Fig. 8a) despite the lack of beluga groups in this area since 2007. The high value of Index 1–5 in Knik Arm (0.247) was likely the result of the large number of calves in August 2006. In August, Index 1–5 indicates that older calves were found in both the Susitna and Knik areas, with percentages being similar in the two areas (Fig. 8b). The Turnagain area had a very low probability of Index 1–5 sightings in both months, but the sample size was sufficient to show that the probability of calves being sampled in a group was significantly less than either of the other two areas (Fig. 8).

The 7-yr average per capita calving rate in August, assuming that Index 1 is unbiased, was 3.5% (SD = 4.3%).

With this average per capita birth rate, the average annual mortality would have to be less than 3.5% for the population to increase (Fig. 9). We do not have a good measure of mortality rate for CIBWs, a minimum value of 2% (SD = 1.2%) for the period 2006–12 can be estimated from the number of carcasses discovered each year (which was likely an underreporting of total mortalities given the difficulty of detecting carcasses in Cook Inlet). When the 6-yr period following 2006 (2007–12) was considered, the average per capita birth rate was 1.9% (SD = 1.1%, 2007–12)) compared to a minimum mortality rate of 1.9% (SD = 1.2%, 2007–12). This suggests that the birth rate was probably at or below the replacement level in those years.

Although the biases in the indices have not been estimated, the range indicates that birth rates per adult female were probably low in most years and the average of the estimated per capita birth rates for the years 2007–12 was about 15% of the level in 2006. If we assume that adult females make up about 30% of the population and that the index was unbiased, then 44% of adult females gave birth in 2006, and in an average year (2006–12), 12% gave birth which was one-third the maximum rate estimated for other Alaska beluga populations (Burns and Seaman[19]). In Cook Inlet, it was likely that the birth rate per adult female was lower than the maximum rate but this cannot be confirmed until we have an estimate of percent mature females within this population.

Conclusions

It is well documented that beluga calves remain in close proximity to their mothers and in the first few months in direct contact with their mothers at least 90% of the time (Krasnova et al., 2006; Suydam, 2009). After the first year, older calves break

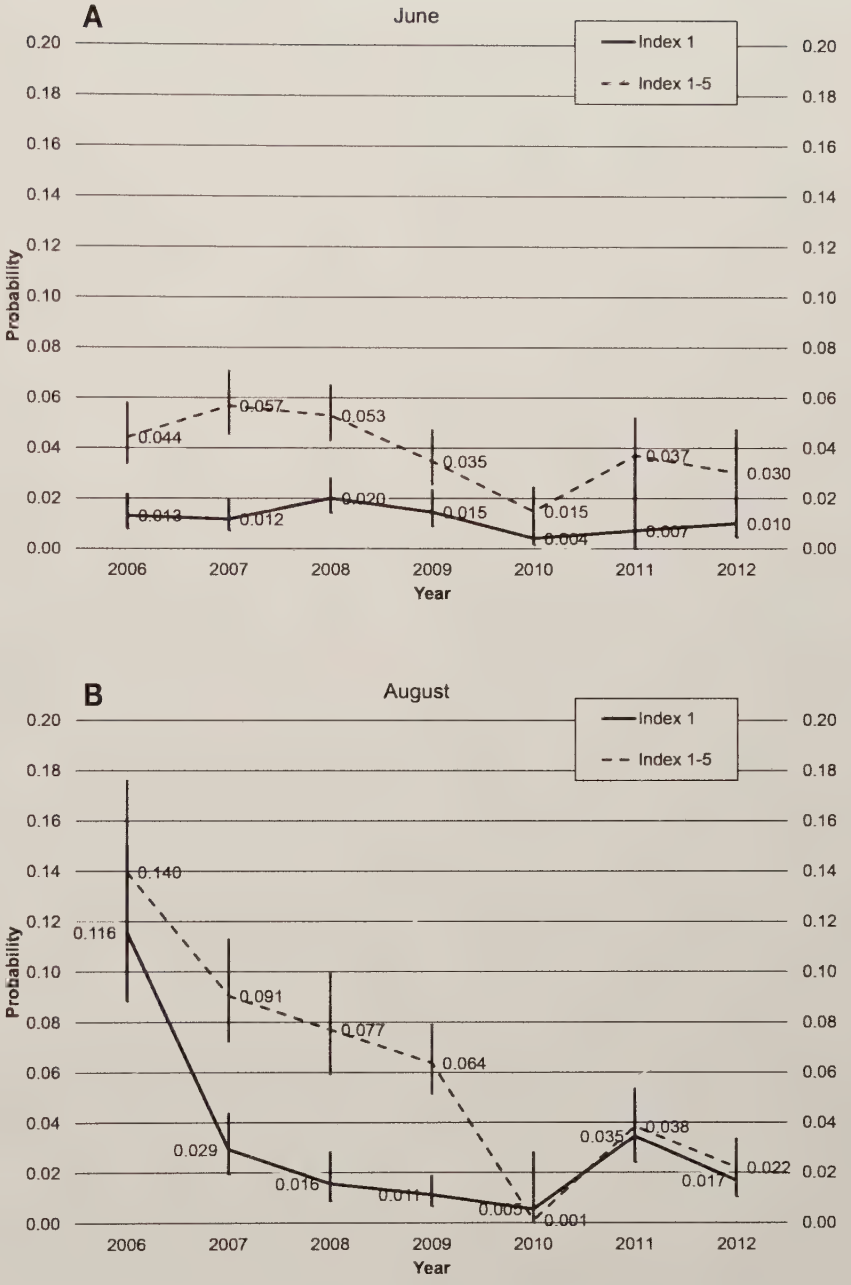


Figure 7.—Probability that a beluga whale drawn at random from the Cook Inlet population would be a calf in June and August for each study year (2006–12). Index 1 includes proximity 1 calves only and represents primarily young-of-the-year. Index 1–5 includes all proximity codes representing juvenile recruitment. Note: Proximity 1 calves were not detected in the August 2010 or June 2011 video sample.

[19]Burns, J. J., and G. A. Seaman. 1986. Investigations of belukha whales in the coastal waters of western and northern Alaska: II. Biology and ecology. U.S. Dep. Commer., NOAA, Natl. Ocean Serv., Anchorage, Alaska, Final Rep., Res. Unit 612, 129 p.

from this close contact but remain near their mothers. This change in behavior after one year of age, allowed us to conclude that Index 1 (calves touching an adult) corresponded closely to the number of calves that were born in the respective year, while Index 1–5 was less well defined and probably represented young-of-the-year, yearlings, and unweaned older calves.

Calves found in our data were consistent with the assumption of a summer birthing period in Cook Inlet. Treating Index 1 as a reliable indication of calving rates, we concluded that more calves were produced in 2006 than in subsequent years. The high calving rate in 2006 may be reflected in lower rates in 2007 and 2008, if we assume many mature females had dependent calves and were not ready to begin a new pregnancy (Brodie, 1971; Sergeant, 1973; Seaman and Burns, 1981). However, 2006's higher calving year does not explain continued low calving rates in subsequent years (i.e., 2009–12) when it could be assumed the same mature female cohort would calve again.

Comparing the two indices, they were very close in 2006 suggesting that the previous years (2004 and 2005) may have been poor, so that the 2006 cohort represented the majority of the young age classes. The indices were again close in 2010 and remained so in 2011 and 2012, after poor reproduction years following 2006. This provided further support to the idea that poor reproductive years occurred prior to 2006.

The poor correspondence between June and the previous August indicated that the June video results from earlier years (1995–2005) would not be useful for estimating calving rates. The high Index 1–5 value for Knik Arm (i.e., almost one-quarter of belugas were calves), resulting from the high calving rate in August 2006, suggests that the Knik area may be an important rearing ground in June, and that the presence of belugas in June may be indicative of high calving rates in the previous years. However, the lack of belugas after 2007 in the Knik

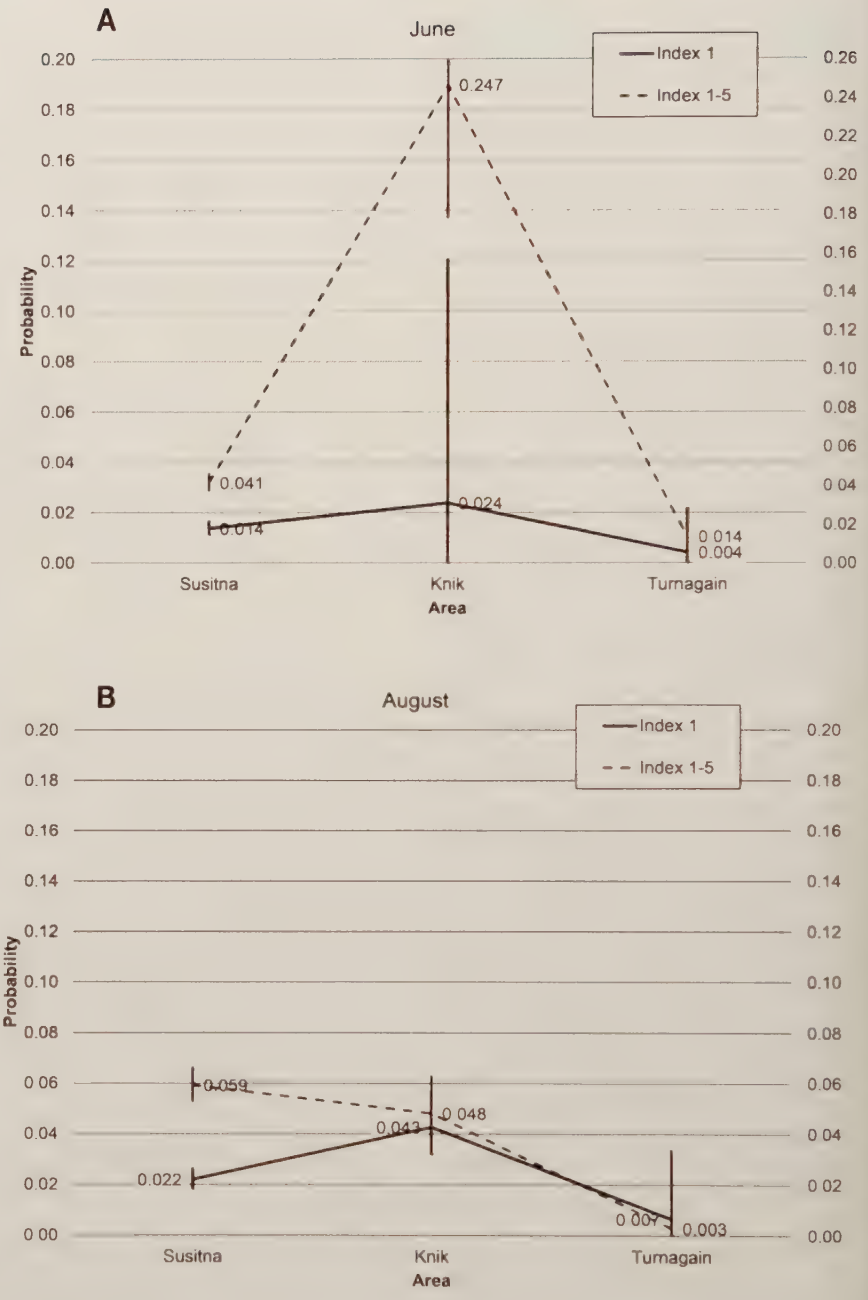


Figure 8.—Probability that a beluga whale drawn at random from the Cook Inlet population would be a calf in June and August for each area (Susitna, Knik, and Turnagain) during the study period (2006–12). Index 1 includes proximity 1 calves only and represents primarily young-of-the-year. Index 1–5 includes all proximity codes representing juvenile recruitment (this index is represented by the secondary axis, which in June is slightly larger than August to accommodate the Knik results). Note: Proximity 1 calves were not detected in Turnagain in August and June, and Knik in June.

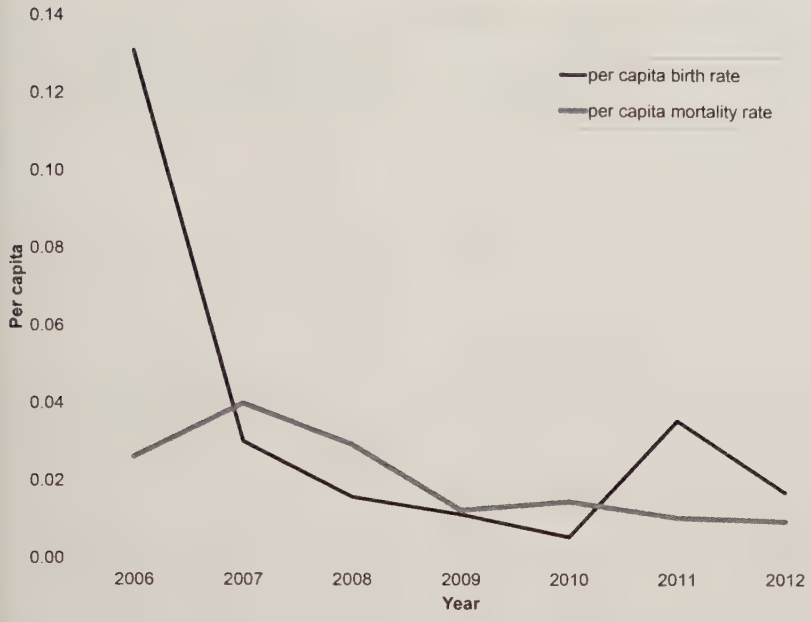


Figure 9.—Per capita birth rate in August compared to the estimated annual per capita mortality rate for the Cook Inlet beluga whale population (2006–12).

area in June may also reflect a change in habitat features in those years unrelated to the number of calves.

While these two indices can be used to monitor the trend in relative number of calves, several key issues remain to be resolved before an estimate of the calving rate of mature females in the population can occur:

1) Surfacing frequency of calves. Young calves are inefficient swimmers compared to adults and will surface much more frequently than an adult. Young-of-the-year calves are nearly always accompanied by an adult (Suydam, 2009). A calf in echelon position with an adult will surface and breathe when the adult surfaces. However, adults accompanying a calf have been observed to bring the calf to the surface without surfacing themselves (Krasnova et al., 2006). Both the increased frequency of surfacing and the appearance of calves surfacing on their own confounds the possibility of an unbiased estimate of calves in the population.
2) Verification of relative image size assumption. We have assumed that the measure of size of the visible portion of the beluga is a constant fraction of the total length and the relative image sizes represent proportional sizes of belugas. The high particulate loads in the waters of Cook Inlet preclude the collection of images of the entire length of each animal, and the current practice of collecting video at an oblique angle further increases the variability in relative size.
3) Unknown fraction of the population that represents mature females. These indices are proportional to the entire population. As the population changes in size, and the age structure recovers from effects of high levels of removals, we expect that the fraction of mature females will change.

Until these issues are resolved, the results presented here represent an index proportional to the per capita calving rate that is suitable for trend analysis only. The current trend from 2007–12, suggests that the birth rate was probably at or below the replacement level.

While the survey effort presented here was sufficient to determine the relative success of calving from year to year, we propose that further work be done to resolve the uncertainties listed above. To address issue 1, we propose attaching time-depth recorders to mothers and their calves for short periods of a few hours to collect surfacing data. For issue 2, we propose surveying a similar population of beluga whales, such as those in Bristol Bay, that occupy waters somewhat less turbid than Cook Inlet, in order to measure full body lengths. To address issue 3, we propose annual biopsy surveys in conjunction with photo-identification surveys to determine the fraction of pregnant females. Finally, with the poor correspondence between August and the following June, we are not constrained by the need to collect comparable data. Therefore, we plan to change the August protocol to collect video beneath the aircraft (vertical rather than oblique) to improve the relative image size measurements.

Understanding calving rates is an important piece of information for the future recovery of this population. Changes in abundance result from the difference between mortality and reproduction from year to year; however, the difference between a good year for calves and a poor year was only a small percent change in the population estimate and less than the statistical error in the estimate. Our ability to estimate the reproductive rate directly gives us a measure that can be compared to environmental data to identify the conditions that promote calving. Calving rates varied more than 10 times between the highest year (2006) and the lowest (2010) and understanding the mechanisms driving this wide variation will be key to developing a successful recovery plan for this population.

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Viability of a Small, Geographically-isolated Population of Beluga Whales, *Delphinapterus leucas*: Effects of Hunting, Predation, and Mortality Events in Cook Inlet, Alaska

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Introduction

Beluga whales, *Delphinapterus leucas*, in Cook Inlet (lat. 59°–61.5°N, long. 149°–154°W), Alaska, make up a small, genetically distinct population that appears to have strong site fidelity to the inlet year-round (O'Corry-Crowe et al., 1997, 2002; Rugh et al., 2004; Hobbs et al., 2005; Shelden et al., 2015). The Cook Inlet beluga whale (CIBW) population declined dramatically in the 1990's, and continued a steady decline through 2012 (Hobbs et al., 2015a), raising concern about its risk of extinction and subsequently leading to listing this distinct population segment as endangered under the U.S. Endangered Species Act (ESA) in October 2008 (NOAA, 2008). Should the CIBW population go extinct, the closest population in Bristol Bay (BB) is 1,500 km away by sea and separated by the Alaska Peninsula that extends three degrees of latitude south of the southern limit of the bay. Similar to CIBWs, satellite-tagged BB whales remained within the bay year-round (Citta et al., In press), thus, it is highly unlikely that beluga whales would repopulate Cook Inlet in the foreseeable future. Extinction of the CIBW population would result in a permanent loss of range for the beluga whale species.

Alutiiq Eskimos and Dena'ina Athabaskan Indians have occupied the coastal areas surrounding Cook Inlet since prehistoric times (de Laguna, 1975). These hunting societies utilized many marine resources including beluga whales. During the 20th century, the Dena'ina in Tyonek (a small village on the west side of Cook Inlet) and Eskimo whalers from communities outside of Cook Inlet hunted beluga whales for subsistence, and there was also periodic sport hunting and large-scale commercial hunts by non-Native hunters (Mahoney and Shelden, 2000). Commercial and sport hunting ended with the introduction of the U.S. Marine Mammal Protection Act (MMPA) in 1972. Subsistence hunting by Alaska Natives was allowed under the MMPA and monitoring by the Alaska Department of Fish and Game (ADFG) indicated that the practice continued from 1972 to the present (Mahoney and Shelden, 2000). During the 1960's, 70's, and early 80's, ADFG conducted a number of aerial surveys that covered parts of Cook Inlet, documenting distribution and numbers of beluga whales (Shelden et al., 2015). The highest estimate of 1,292 beluga whales reported during these surveys was based on counts made in August 1979 (Calkins[1]).

In June 1993, the National Marine Fisheries Service (NMFS) began comprehensive, systematic aerial surveys of the beluga whale population in Cook Inlet (Rugh et al., 2000, 2005,

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[1]Calkins, D. G. 1989. Status of belukha whales in Cook Inlet. *In* L. E. Jarvela and L. K. Thorsteinson (Editors), Proceedings of the Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information update meeting, 7–8 Feb. 1989, Anchorage, Alaska, p. 109–112. U.S. Dep. Inter., Minerals Manage. Serv., OCS Study, MMS 89-0041.

ABSTRACT—A genetically distinct population of beluga whales, Delphinapterus leucas, *in Cook Inlet, Alaska, displays strong site fidelity to the inlet year-round. A population viability analysis (PVA) model was developed to evaluate this population's risk of extinction and decline over 50 and 100 years. Model assumptions and parameter sensitivity were tested by varying survival and fecundity rates, frequency of catastrophic events, predation level, and group mortality events and carrying capacity. While the different model scenarios showed considerable variation in extinction risk within 50 years (0–18%), and 100 years (0–38%), and probability of decline (1–71%), only the assumption of an intrinsic rate of growth greater than 2%, among the least likely scenarios (Models A, C–E), reduced the risk of further decline to 1–2%. Almost all model scenarios that included unusual mortality events (Models G–L) had probabilities of extinction within 50 years (2–18%, with the exception of Model G = 0%) unlike scenarios without (0–1%). Both predation and group mortality events were shown to create thresholds below which the population could not recover. Models including threshold effects had probabilities of extinction as much as 25% higher than similar models without. In Model B, with no threshold effects, and with no subsistence hunt after 2014, the population declines in 53% of the cases, with a probability of recovery in 100 years of 14%. The model scenarios that best fit the existing Cook Inlet beluga whale data (Models B, F, M–O) included a per capita mechanism increasing mortality (Models B, F, O), mortality from killer whale,* Orcinus orca, *predation (Models F, N, O), or a reduction in Cook Inlet carrying capacity (Models M–O). Model scenarios B, F, K, M–O were used to estimate the range of the probability of extinction: these had a probability of decline between 42% and 71%, and a probability of extinction between 0% and 14% in 100 years.*

2010; Shelden et al., 2013, 2015). Survey results showed a decline in abundance of nearly 50% between 1994 and 1998, from an estimate of 653 whales to 347 whales (Hobbs et al., 2000a). Concern over the high level of human-caused mortality on this whale population prompted NMFS to designate it as depleted under the MMPA (NOAA, 2000) and to regulate the Native Alaskan subsistence hunt (Mahoney and Shelden, 2000).

With a limited hunt between 1999 and 2014 (a total of five whales taken), it was anticipated that the population would begin to recover though this has not been the case (Hobbs et al., 2015a). Hunters indicated a preference for large, white-skinned beluga whales (presumably adults) (Mahoney and Shelden, 2000; Huntington, 2000); therefore, it is conceivable that the population had a deficit of reproductive-age females, which could be inhibiting recovery through reduced calf production (Hobbs et al., 2015b). However, the hunt may not be the only risk factor behind the continued decline of this population.

In addition to the decline in numbers, the population has undergone a contraction within its range (Rugh et al., 2010; Shelden et al., 2015). Summer surveys during the 1970's found beluga whales distributed throughout much of the upper inlet and into the lower inlet around Kalgin Island. Since the mid-1990's, from 96% to 100% of beluga whales now congregate in shallow areas near river mouths in the upper inlet during the summer months (Rugh et al., 2010; Shelden et al., 2015).

It is unknown if this contracted distribution is a result of changing habitat (Moore et al., 2000), prey concentration, or predator avoidance (Shelden et al., 2003), or can simply be explained as the contraction of a reduced population into a small number of preferred habitat areas (Goetz et al., 2007, 2012), such as in a "basin" model (MacCall, 1990). While the recent trends in abundance and range are well documented, little is known about other mechanisms influencing the recovery of this beluga whale population.

The CIBW population may be less resilient to natural perturbations or anthropogenic impacts because of its small size and isolation. With such a small population in a relatively restricted area, a substantial portion of the population could rapidly be exposed to events such as infectious disease outbreaks, volcanic eruptions, fish run failures, and toxic spills (Moore et al., 2000; Vos and Shelden, 2005).

Additionally, the grouping behavior of the population could potentially magnify exposure to even very localized anthropogenic and environmental hazards. During the summer months, Cook Inlet beluga whales tend to be found in 2–10 groups of a few individuals to over 200 whales in a single group (Hobbs et al., 2015a; Shelden et al., 2015) in areas such as Knik Arm, the Susitna Delta, and Chickaloon Bay–Turnagain Arm (Fig. 1). If a group of 200 whales were exposed to a toxic spill, this would represent over half of the current population.

The population's small size and grouping behavior also mean that a relatively large percentage of the population could be involved in a single mass stranding (Vos and Shelden, 2005), or entrapped in ice similar to events documented in other beluga whale populations (Siegstad and Heide-Jørgensen, 1994; Heide-Jørgensen et al., 2002), magnifying the effect on the population's recovery. Given the population's restricted range, particularly in summer, declines in local fish stocks, such as Pacific salmon, *Oncorhynchus* spp., runs in the rivers in Cook Inlet (Eggers and Irvine, 2007; Dischner[2]), could cause nutritional limitation in the population. Predation may also be a factor in the recovery of the population; between 1999 and 2014 a total of 10 beach-cast and floating carcasses reported to the NMFS Alaska Regional Office (NMFS[3]) were determined to be related to killer whale, *Orcinus orca*, predation. Three of the carcasses were lactating females, so an additional 3 calves were thought to have died though carcasses were not found (NMFS[3]).

Therefore, potential factors for the delay in recovery include reduced fecundity because the mature female segment of the population is depleted, reduced fecundity or survival due to reduced prey, predation by killer whales, and risks associated with a contracting range and grouping behavior of the whales. To examine these issues, we conducted a population viability analysis (PVA) by developing a detailed population model that included age and sex structure as well as small population effects. Small population effects taken into account included demographic stochasticity, hunt mortality, density-dependent and density-independent effects, constant mortality effects (e.g., predation), unusual mortality events (e.g., catastrophes), and risks associated with the grouping behavior of these whales.

The population model implicitly considers the time lags inherent in long-lived populations where sexual maturity does not occur for many years (Litzky, 2001), and it was projected into the future to examine extinction risk under different risk factor scenarios for CIBWs. The rather detailed population model and Bayesian framework were programmed in FORTRAN and used existing data from the Cook Inlet population and similar beluga populations.

The parameters of the model were estimated by fitting the population model to the abundance time series and hunt data. Variations of the model, termed model scenarios, were developed to investigate a number of hypotheses for the delay in recovery and these hypotheses were statistically

[2]Dischner, M. 2013. Inlet drift fishermen file suit over salmon management. Alaska J. Commer., Feb. Iss. 3 [http://www.alaskajournal.com/Alaska-Journal-of-Commerce/February-Issue-3-2013/Inlet-drift-fishermen-file-suit-over-salmon-management/].

[3]NMFS. 2015. Draft recovery plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Alaska Region. Off., Protected Resour. Div., Juneau, AK, 274 p.

compared using Bayesian model selection, which provides the probability of each model scenario (or hypothesis) given the data, through the use of the Bayes factor. We also examine future recovery and extinction risk under each hypothesis.

We considered the following hypotheses (H) explicitly:

H1) The population has not yet begun to recover but it will under the status quo—there has been a delay (time lag) in recovery due to a depletion of mature females, and the population will begin to increase once it rebuilds the mature female segment of the population.

H2) The subsistence hunt was not the sole cause of the decline observed since 1994 and the population has not begun to recover because an as yet unidentified population wide stressor (e.g., nutritional stress, disease, contaminants, noise, loss of key habitat) has caused a decrease in fecundity and/or survival, resulting in a negative growth rate. The population will not begin to recover in the future without a change in the fecundity or survival of the population.

H3) The population has not begun to recover because the reduction in population size from hunting has led to it falling into a "predator pit"—a numerically constant level of predation was sustained by the population when it was >1,000 animals, but at the current population level, predation prevents recovery.

H4) The population has not begun to recover because the level of predation from killer whales coincidentally increased around the time of the population decline (e.g., due to a prey shift by the killer whale population).

H5) The population has not begun to recover because the reduction in population size from hunting and subsequent retraction in range has led to a greater proportion of the population being vulnerable to "catastrophic" mortality events, such as disease outbreaks, oil or toxics spills, volcanic eruptions, or failure of several Pacific salmon runs in one year.

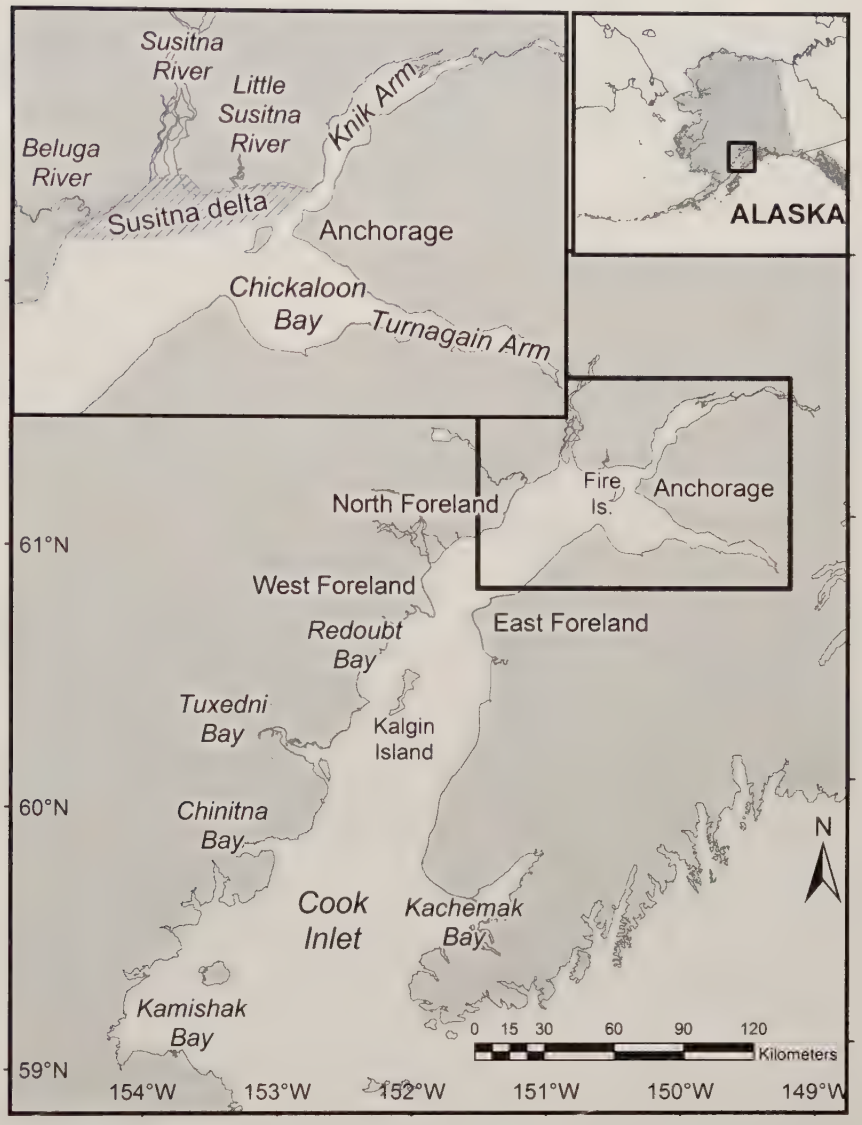

Figure 1.—Cook Inlet, Alaska, and place names mentioned in the text. Beluga whales are typically found in the upper inlet (inset) during the summer.

H6) The population has not begun to recover because the reduction in population size from hunting and subsequent retraction in range has led to fewer social groups in the population, such that a greater proportion of the population is vulnerable to mortality events that affect all or a large fraction of a single social group.

H7) The population has not begun to recover because of a combination of killer whale predation, per capita effects, and increased catastrophic or group mortality following population decline.

H8) The population has not begun to recover because the carrying ca-

Table 1.—Time series of Cook Inlet beluga whale data used in the Bayesian analysis. Estimated abundance was calculated from observer and video data. Hunt landings and struck and lost data were from Mahoney and Shelden (2000) and NMFS Alaska Regional Office (NMFS, text footnote 3). Where conflicting sources occurred, all are listed and the range of values is used. Note that killed but lost are included with the struck and lost.

Year	Estimated abundance	Abundance CV	Hunt landings (struck and lost)
1994	653	0.24	19(2)
1995	491	0.21	60(14), 52(22), 42(26)
1996	594	0.20	49(49–98)
1997	440	0.13	35(30–40), 35(35)
1998	347	0.17	21(21)
1999	367	0.09	0(0)
2000	435	0.14	0(0)
2001	386	0.10	1(0)
2002	313	0.10	1(0)
2003	357	0.08	1(0)
2004	366	0.13	0(0)
2005	278	0.10	2(0)
2006	302	0.10	0(0)
2007	375	0.08	0(0)
2008	375	0.11	0(0)
2009	321	0.11	0(0)
2010	340	0.08	0(0)
2011	284	0.09	0(0)
2012	312	0.13	0(0)
2014	340	0.08	0(0)

pacity of Cook Inlet for belugas has declined during the population decline.

We use the Bayes factor to compare model scenarios and test hypotheses. The posterior sample of each model scenario was projected forward 100 years to estimate the probabilities of population recovery, increase, decline, and extinction under each hypothesis. The results of the model comparison were then used to identify the best model scenarios for assessing population viability.

Methods

The PVA was conducted by fitting a population model for the CIBW population to available abundance data using Bayesian statistical methods. In a Bayesian analysis, prior distributions for the model parameters are combined with a likelihood function for the data to give posterior probability distributions for the parameters, from which inference is based (Gelman et al., 1995; Ellison, 1996; Wade, 2000).

Prior distributions for the model parameters were specified using information from the CIBW population or, if necessary, from other beluga populations. The population model was initiated in 1979 (when the population was thought to be near carrying capacity) which allowed 15 years for the age distribution to accommodate to the presumed hunting removals before the parameters of the model were estimated by fitting the model to a time series of abundance estimates for the years 1994–2014 (Table 1). The population model was additionally projected 100 years into the future from 2014.

The analysis can be viewed as having two stages, a parameter estimation stage and a future projection stage, but it was conducted as a single integrated analysis. This ensures that the PVA projections are fully consistent with the available data (Wade, 2002). Additionally, Bayesian model selection methods were used to compare how well different model scenarios fit the data. The interpretation of the results focuses on the estimated probabilities of extinction or recovery and realized rates of growth or decline.

The methods below are presented in three stages which proceed from the general to the specific. First the population model is described and the various components of the survival and reproductive models are developed mathematically. This is followed by a section which presents the parameters and prior distributions specific to the modeling of the CIBW population. Finally, the methods for developing the posterior distributions, conducting the inference, and testing of hypotheses are described. Comparisons between the model development and the parameter values and prior distributions used in the analysis are presented in the Parameter Estimation section. The relationship between the hypotheses model scenarios and the model components included in each scenario are presented in the Model Scenario Comparison and Selection section.

Population Model

An age and sex structured population model was developed using life history and population parameters from Cook Inlet and other beluga whale populations (Table 2).

Age and Sex Structure

Age-classes included each year up to maturity to account for the time lag from birth to sexual maturity (Litzky, 2001), and the preference of Native subsistence hunters for adult animals. Females and males were modeled separately to incorporate sex structure into the model and allow for unequal hunt of each. For both males and females, all adults greater than the age of sexual maturity (8+ growth layer groups (GLGs) Table 2 were lumped together for convenience.

Demographic and Environmental Stochasticity

The numbers of individuals in each age- and sex-class were tracked as integers. Births and deaths were modeled as discrete integer events using binomial distributions with the expected birth rate and survival rate, respectively. Births were modeled as a binomial draw using the birth rate and the total number of mature females. Survival from one age and sex class to the next was modeled as a binomial draw using the survival rate and the number of individuals in that age and sex class. The use of a binomial distribution in the population model incorporates demographic stochasticity, the random variations in the number of individuals that happen to die or reproduce in a given year even when the expected rate remains constant (Begon et al., 1996:927). Recorded takes

Table 2.—Review of female beluga life history parameters from the published literature. Growth layer groups (GLGs) obtained from beluga teeth were reported instead of ages. Past studies (e.g., source 1) used two GLG layers to represent one year of growth; however, recent studies support one GLG per year of growth (Stewart et al., 2006; Lockyer et al., 2007; NAMMCO: http://septentrio.uit.no/index.php/NAMMCOSP/issue/view/236).

Parameters	Data	Source
Age at sexual maturity	7–13 GLGs (mean = 10, no sample size), 5–6 to 11–12 GLGs (mean = 9, *n* = 33)	2A
	9–11 GLGs (mean = 10, no sample size)	1A
	8–9 GLGs (0%), 10–11 GLGs (33%), 12–13 GLGs (94%), 16–17 GLGs (100%)(*n* = 207)	3A
	9.1 ± 2.8 GLGs (*n* = 23)	4
	50% at 8.25 GLGs (*n* = 87)	5
Age at color change (gray to white)	12 GLGs (minimum age)	1
	14 GLGs (minimum from Mackenzie Delta),	2
	17 GLGs (minimums from western Hudson Bay)	2
	9–10 GLGs for males, 10–12 GLGs for females	5
Age at 1st conception	54% at 8–9 GLGs (*n* = 12 of 22)	3
	41% at 10–11 GLGs (*n* = 9 of 22)	3
	4% at 12–13 GLGs (*n* = 1 of 22)	3
	8.27 GLGs (SE = 2.88, *n* = 87)	5
Age at senescence	42–43 GLGs (arbitrarily assumed by Kleinenberg)	1
	40 GLGs (corpora level off and decline)	5
Pregnancy and birth rates	With small fetuses: 0–11 GLGs (0.055), 12–21 GLGs (0.414), 22–45 GLGs (0.363), 46–57 GLGs (0.267), 58–77 GLGs (0.190). With full-term/neonate: 0–11 GLGs (0), 12–21 GLGs (0.326), 22–45 GLGs (0.333), 46–51 GLGs (0.278), 52–57 GLGs (0.182), 58–77 GLGs (0.125)	3
	0.41 (w/small fetuses); 0.56 (w/full term fetuses or neonates)	5
Lifespan	60–61 GLGs	1
	50–53 GLGs	2B
	>60 GLGs (oldest female estimated at 70+ GLGs)	3
	46 GLGs (male, tooth worn w/no visible neonatal line)	5
	57 GLGs (female)	5
Adult annual survival	0.9064 (average based on mean annual mortality rate = 0.0936)	3
	0.91–0.92	6. 7
	0.842 and 0.905 (assuming 2GLGs/yr vs. 1 GLG/yr)	8
	0.96–0.97	9
	0.935	10
Immature annual survival	0.905 (for neonates in first half year of life, mortality rate = 0.095)	2
	0.955 (based on pilot whale net recruitment)	11
Reproductive rate	0.13 (ratio of calves to adult females, modeled)	2
	0.143 (ratio of calves to adult females)	2
	0.114–0.117 (ratio of calves to whales)	2
	0.104 (a model population of 1,000 that included 94 calves)	3
	0.097 (ratio of calves to whales)	7
	0.08–0.10 (ratio of calves to whales)	11
	0.12 (ratio of calves to whales)	12
	0.056–0.10 (ratio of calves to whales)	13
	0.08–0.14 (ratio of calves to whales)	14
	0.08 (unknown)	15
Lactation period	At least 2 years	1
	21 months on average	2C
	23 months (range:18–32 months)	7A
Calving interval	3 years	1, 2D, 3B
	2–3 years	5
	>2 years	7B

[1]Brodie, P. F. 1971. A reconsideration of aspects of growth, reproduction, and behavior of the white whale (*Delphinapterus leucas*) with reference to the Cumberland Sound, Baffin Island, population. J. Fish. Res. Bd. Can. 28:1309–1318. A. [Canada] Cumberland Sound, Baffin Island, population, *n*=124 animals (86% captured in nets which biased the sample toward females with newborns), ASM excluded one immature animal age 15 GLGs, sample sizes not provided though Fig.3 appears to show 51 females in the sample.

[2]Sergeant, D. E. 1973. Biology of white whales (*Delphinapterus leucas*) in western Hudson Bay. J. Fish. Res. Bd Can. 30:1065–1090. A. [Canada] Churchill and Whale Cove in western Hudson Bay, additional information from the Mackenzie Delta, Beaufort Sea and data collected by Khuzin (sample of 33) in the Kara/Barents seas, Russia. B. Found differences in maximum age based on sampling technique. Life span of netted whales tended to be lower (40 GLGs at Whale Cove) than those selected and harpooned (50 GLGs at Churchill, 53 GLGs at Mackenzie Delta). Similar results were reported by Brodie (1971) for whales netted in Cumberland Sound (40 GLGs). C. based on length of gestation (14 months) x 33 lactating/22 pregnant whales. D. In 7 of the 29 pregnant females examined from Whale Cove, lactation was still occurring and for some analyses a 2 year calving cycle was assumed for 25% of the adult female population (p. 1084). Concluded "overlap of pregnancy and previous lactation is infrequent so that calving occurs about once in three years.

[3]Burns, J. J., and G. A. Seaman. 1986. Investigations of belukha whales in coastal waters of western and northern Alaska. II. Biology and ecology. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 56(1988):221–357. [Northwest Alaska]; A Sampling occurred in June, a time when most Alaskan belugas are born. It is possible non-pregnant 8–9 GLGs belugas would have conceived before their 10–11 GLGs birth date. B. For some female belugas. This was a tentative conclusion based on high conception rates noted in some females between the ages of 12–13 GLGs and 44–45 GLGs.

[4]Robeck, T. R., S. L. Monfort, P. P. Calle, J. L. Dunn, E. Jensen, J. R. Boehm, S. Young, and S. T. Clark. 2005. Reproduction, growth and development in captive beluga (*Delphinapterus leucas*). Zoo Biol. 24:29–49. [captive belugas].

[5]Suydam, R.S., 2009. Age, growth, reproduction, and movements of beluga whales (*Delphinapterus leucas*) from the eastern Chukchi Sea. Ph.D. dissert., Univ. Wash., 152 p.

[6]Allen, K., and T. Smith. 1978. A note on the relation between pregnancy rate, age at maturity and adult and juvenile mortality rates. Rep. Int. Whal. Comm. 28:477–478. Reviewed in Braham, 1984.

[7]Braham, H. W. 1984. Review of reproduction in the white whale, *Delphinapterus leucas*, narwhal, *Monodon monoceros*, and Irrawaddy dolphin, *Orcaella brevirostris*, with comments on stock assessment. Rep. Int. Whal. Comm. (Spec. Issue 6):81–89. A. analysis of data collected by Seaman and Burns (1981). B. based this assumption on data from Brodie (1971) and Sergeant (1973) that age at first pregnancy is 6 years (12 GLGs) and last pregnancy is about 21 years (42 GLGs) resulting in a 14–15 year breeding period, which would allow

Table notes continued

from the Native subsistence hunt were partitioned among adult males, adult females, and the older age classes of immature animals of both sexes. Recorded takes were directly subtracted from each class (Table 1), after modifications to account for uncertainty, such as allocation to sex and struck and lost whales (explained below).

No environmental time series and mechanism has been identified as impacting survival or fecundity of the CIBW population, however demographic stochasticity does not explain the variation observed in the calf index (Hobbs et al., 2015b) or the annual numbers of deaths recorded (NMFS[3]). To account for this observed variation we included a correlated random variation scaled to the variation in the two data sets.

Population Projection

The CIBW population was projected annually for females (f) and males (m) as:

$$f_{0,t} = \begin{cases} B\left(f_{mat,t}, b_t/2\right) \text{ if } f_{mat,t-1}, m_{mat,t-1} \geq 1 \\ 0 \qquad\qquad otherwise \end{cases}$$

$$m_{0,t} = \begin{cases} B\left(f_{mat,t}, b_t/2\right) \text{ if } f_{mat,t-1}, m_{mat,t-1} \geq 1 \\ 0 \qquad\qquad otherwise \end{cases} \qquad (1)$$

$$f_{a+1,t+1} = B\left(f_{a,t}, s_{a,t}\right) \qquad \text{for } a = 0 \text{ to } (a_{mat} - 2)$$

$$m_{a+1,t+1} = B\left(m_{a,t}, s_{a,t}\right) \qquad \text{for } a = 0 \text{ to } (a_{mat} - 2)$$

$$f_{mat,t+1} = B(f_{mat,t}, s_{f,mat,t}) + B(f_{mat-1,t}, s_{mat-1,t})$$

$$m_{mat,t+1} = B(m_{mat,t}, s_{m,mat,t}) + B(m_{mat-1,t}, s_{mat-1,t})$$

Where a is age and $B(n, p)$ is a binomial distribution with n trials and probability p, the variables s and b represent survival and birth probabilities, respectively, which are elaborated below.

Birth Rate

Density dependence was included in the birth rate in the form of the commonly-used generalized logistic function (Breiwick et al., 1984).

$$b_t = \left[b_0 - (b_0 - b_K)\left(\frac{N_t}{K}\right)^z + b_0 \sigma_b \varepsilon_t \right] B_c \qquad (2)$$

$$\varepsilon_t = \rho \varepsilon_{t-1} + \sqrt{1-\rho^2}\,\omega_t$$

$$B_c = \frac{1 - s_0}{1 - s_0 S_c}$$

K represents the population size at carrying capacity or, in other words, the population size that the population would reach if there is no reduction in birth rate or survival rate except due to density dependence and there is no environmental variation. The parameter z controls the shape of the density-dependence, where values of $z > 1$ mean that most of the density-dependent response occurs close to K. σ_b is a scaling factor to the effect of environmental variation on birth-rate relative to the effect on survival, ε_t is a stationary, correlated, random environmental deviation with mean = 0, variance = σ^2, and correlation = ρ (Morris and Doak, 2002:139) and ω_t is a normal random deviate with mean = 0 and variance = σ^2, the same series was used for both birth rate and survival. B_c is a constant fractional reduction in per capita birth rate such as would occur as a result of chronic under nutrition or high contaminant loads; s_0 is the survival rate for the unaffected population when it is small and S_c is the survival rate reduction from the per capita effect (described below). B_c was set to 1 except in scenarios with the per capita effect where B_c was the inverse of the proportional increase in mortality so that this effect was split approximately equally between mortality and reproduction. Note that without environmental variation, when the population is at carrying capacity so that $N_t = K$, then $b_t = b_k B_c$, and when the population is small so that N_t is close to zero, then $b_t = b_0 B_c$.

Survival Rates

The variables $s_{0,t}$, $s_{a,t}$ $s_{f,mat,t}$, and $s_{m,mat,t}$ are annual survival rates by age and sex. They are the products of two

Table notes contnued

only 6 calves rather than the 10 calves predicted by the authors if a female's reproductive cycle is three years. However, this calculation was based on 2 GLGs = 1 year, using 42-12 = a 30 year breeding period and a 3-year reproductive cycle would produce 10 calves.

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[14]Davis, R. A., and C. R. Evans. 1982. Offshore distribution and numbers of white whales in the eastern Beaufort Sea and Amundsen Gulf, summer 1981. Report for SOHIO Alaska Petroleum Co., Anchorage, and Dome Petroleum Ltd., Calgary, Alberta, by LGL Ltd. 76 p. [eastern Beaufort Sea and Amundsen Gulf].

[15]Breton-Provencher, M. 1981. Survey of the beluga whale population in the Poste-de-la-Baleine region. Unpubl. Doc. Submitted to Int. Whal. Comm. (SC/32/SM16) [Paper available from http://www.iwcoffice.org/]. [Poste-de-la-Baleine region].

components: 1) S_t, a population wide survival rate that is independent of age and sex, and determined by density dependence; and 2) $S_{h,age\text{-}sex,t}$, an age and sex dependent survival rate determined by hunting activity (h) on adult males, adult females, and immature (j) whales.

$s_{0,t} = S_t\, s_{f,mat,t}$, which accounts for a calf's dependence on its mother; (3a)

$s_{a,t} = S_t$, for a = 1 to 3; (3b)

$s_{a,t} = S_t\, S_{h,j,t}$, for a = 4 to mat-1; (3c)

$s_{f,mat,t} = S_t S_{h,f,t}$, for adult females; and (3d)

$s_{m,mat,t} = S_t S_{h,m,t}$ for adult males (3e)

Hunt Mortality

The hunt mortality was modeled as the sum of the recorded landed whales with different rates for adult males, adult females, and immature whales. Additional mortality was added to account for whales that were struck and lost (injured or killed during a hunt but not retrieved and landed), specified by year. The total hunt mortality (H_t = landings + struck and lost) was allocated to age and sex class using a binomial distribution and parameters controlling the expected age and sex bias in the hunt:

$$H_{j,t} = B(H_t,\ Pr(Hunt\ Immature)) \quad (4a)$$

$$H_{m,t} = B(H_t - H_{j,t},\ Pr(Hunt\ Male)) \quad (4b)$$

$$H_{f,t} = H_t - H_{j,t} - H_{m,t} \quad (4c)$$

Where t is the year, $H_{j,t}$ is the number of immature whales killed, $H_{m,t}$ is the number of mature male whales killed, and $H_{f,t}$ is the number of mature female whales killed. The *Pr(Hunt)* were chosen from a Beta distribution prior for each case of the model, as described below. The numbers of whales killed were translated into survival rates from the hunt as:

$$NV_t = \sum_{a=4}^{mat-1} f_{a,t} + m_{a,t} \quad (5a)$$

$$S_{h,j,t} = 1 - \frac{H_{j,t}}{NV_t} \quad (5b)$$

$$S_{h,m,t} = 1 - \frac{H_{m,t}}{m_{mat,t}} \quad (5c)$$

$$S_{h,f,t} = 1 - \frac{H_{f,t}}{f_{mat,t}} \quad (5d)$$

representing survival of immature whales, mature males, and mature females, respectively. NV_t is the total number of immature whales vulnerable to hunting. The hunt survival parameters are formulated as survival rates so that if there is no hunt mortality the rates all equal 1.

Population Level Survival Rate

Density dependence was included in the population level component of survival. Variations of the survival model were also specified to allow for (depending upon the model scenario) changes in survival from other factors. The other factors include 1) a constant declinc in the survival rate (a "per capita impact") such as might occur as a result of chronic under nutrition or high contaminant loads, 2) a constant numeric decline in survival (e.g., one additional whale per year) such as could occur from density-independent predation by killer whales, 3) occasional unusual mortality events ("catastrophes") that affect a percentage of the entire population, and 4) occasional mortality events ("group mortality") that affect an entire social group, which is a form of an Allee effect (Allee et al., 1949) as this mortality has a greater effect as the population becomes smaller and has fewer social groups. The population level survival rate is:

$$S_t = \left[s_0 - (s_0 - s_k)\left(\frac{N_t}{K}\right)^Z + \varepsilon_t \right] S_c S_{p,t} S_{e,t} S_{g,t} \quad (6)$$

Where S_c is the constant per capita impact, $S_{p,t}$ is the predation effect, $S_{e,t}$ is the catastrophe effect, and $S_{g,t}$ is the group mortality effect (details on calculations of these factors are found below). ε_t is the same environmental series used in the birth rate. Note that these additional mortality factors are formulated as multiplicative adjustments to S_t that act independently. These specific survival models can then be employed together or separately.

Killer Whale Predation Mortality

Predation from killer whales was modeled as a density-independent survival factor, meaning the expected number of additional deaths will remain the same regardless of the CIBW population size. This assumes that killer whales prey on belugas irrespective of the size of the population (i.e., there is no numerical or functional response by the predator). Killer whale predation mortality was modeled in this way because predation on CIBWs would represent such a small fraction of the annual diet of mammal-eating killer whales in the region that there would be no predation response to the density of CIBWs.

This means that predation mortality was assumed to be determined by factors such as the frequency of killer whale visits to the upper inlet. By modeling predation this way, the same number of predation deaths was a larger percentage of the population size when the population was smaller, and increased the risk to the population. Eventually, a population may decline to the point where predation cannot be sustained and thus prevents its recovery, this has been termed a "predator pit."

Predation mortality from killer whales was specifically modeled as

$$S_{p,t} = \frac{N_t - C_s C_p}{N_t} \quad (7)$$

where C_s is estimated as the average number of observed deaths from killer whales during the time period 1999 to 2014, and C_p represents a scaler to allow for decreasing or increasing the level of killer whale predation in the model scenario (e.g., a value of 2 means that twice as many predation deaths occurred than were observed from 1999 to 2014). Note that $S_{p,t}$ was also constrained to be no less than 0 for the case where the constant number of expected killer whale predations was greater than the population size.

Catastrophes (Unusual Mortality Events)

Occasional unusual mortality events, including but not limited to disease outbreaks, mass strandings, volcanic activity, toxic spills, and failure of Pacific salmon runs, could potentially impact a substantial portion of the CIBW population and were, therefore, important to consider. Catastrophes were modeled as mortality events where an additional specified fraction of the population died in a given year:

$$S_e = 1 - M_e B(1, P_{Me}) \quad (8)$$

where M_e is the probability of mortality during an unusual mortality event (e.g., where a value of 0.1 means that 10% of the population was expected to die, in addition to the density-dependent mortality that takes place); and P_{Me} is the binomial probability of an unusual mortality event occurring in a given year. The catastrophe survival factor models random events that affect the entire population. If P_{Me} equals 0, no catastrophic events occur because $S_e = 1$.

Group Mortality

Given that a large percentage of the CIBW population may aggregate in a single behavioral group at one time, another way to model an unusual mortality event would be to have it affect a single social group. Events that could affect an entire social group at the same time include entrapment in ice, becoming stranded in a shallow area at low tide, a local toxic spill, or a stranding related to an acoustic event.

A group mortality event can be viewed as a different form of a catastrophic mortality event, but where the size of the social group and the mortality rate within the group determines the number of whales that die, rather than being specified as a fixed proportion of the population. Therefore, catastrophes and group mortality were not included together in any model scenario but were instead viewed as alternative ways of modeling unusual mortality events.

To model this type of mortality affecting all or part of a single social group, a group survival factor is modeled as:

$$S_{g,t} = 1 - \left(\frac{M_g G_t}{N_t}\right) B(1, P_g) \quad (9)$$

where P_g is the probability of an event occurring in a given year that would lead to a group mortality; M_g is the probability of mortality for individuals in the group affected by a group mortality event; and G_t is the size of the affected group drawn for each event from the observed distribution of group sizes (truncated at N_t). Whether or not an event occurs in a given year is determined by an annual draw from a binomial distribution with probability of occurrence in a given year of P_g such that either one or no event occurs in that year.

For this factor, groups were collections of belugas in a locale and may include several social groups in proximity to each other or possibly one large group. If the group size drawn was equal to the population size, then G_t was replaced with N_t and the Group Mortality model was the same as the Catastrophe model. The risk of an event remained the same but the group size changed. The individual risk in this model at a particular population size is proportional to the ratio of the average group size in the population to the population size, which increases as abundance declines because there are fewer groups, so the chance of being in the group affected increases.

This model implies that only one group is affected by any event so, for example, a localized toxic spill at the Port of Anchorage would affect a group in Knik Arm but not impact groups in other areas such as the Susitna Delta or Chickaloon Bay. Similarly, this models a group stranding event that affects only the group trapped by a falling tide. As the population increases and divides into more groups, it becomes less vulnerable to these sorts of events. If $P_g = 0.0$, no group mortality event occurs in any year.

Starting Population Size and Initial Age Distribution

The model parameters were estimated by fitting the population model to abundance data starting in 1994, when NMFS began an annual series of systematic counts with applied correction factors for the CIBW population estimates (Hobbs et al., 2015a). The 1979 abundance estimate was from a single day survey to which Calkins[1] applied a correction factor based on radio-tag data from the Bristol Bay population (Frost et al., 1985). This estimate was used as the basis for the prior distribution for population size in the start year of 1979, the population was then projected forward to 1994 to allow 15 years for the hunt to affect the sex and age distribution of the population. The population was initialized in 1979, with a stable age distribution calculated from the life-history parameters with the survival rate associated with the population size in 1979, and with a population growth rate of 0.0 (λ set to 1.0, see below). Age and sex classes were filled by randomly sampling as a multinomial distribution from the stable age distribution until the initial population size was reached.

Prior Distributions

Values for model parameters were taken from data available on beluga populations (Table 2). For parameters for which little data were available or inference was intended, prior distributions were devised as described below. Some parameters were fixed at a single value. A "healthy" population

model scenario was specified with a growth rate that was considered to be typical of increasing cetacean populations and no additional mortality from per capita effects, predation, catastrophes, or group mortality. Other model scenarios were specified that included additional mortality as a fixed number of deaths or fixed rate or drawn from a prior distribution of deaths or rates from those factors. The fit of the different model scenarios to the data were compared using Bayesian model selection methods (detailed below).

Annual Growth Rate (λ)

The population rate of increase (λ) is not among the parameters of the population model above; however, for given values of the life history parameters (e.g., survival, birth rate, age of sexual maturity) in the population model, λ is determined, because they are functionally related (Euler, 1760; Lotka, 1907). We use a simplified version of the population model as follows. Treating s and b, as constant parameters (rather than probabilities), we have a deterministic projection of the expected values of the abundance and individual age and sex classes. Considering only females, we have a recursion model in expected births by year:

$$f_{0,t} = \frac{b}{2} f_{mat,t} = \frac{b}{2} s^{a_{mat}+1} f_{0,t-a_{mat}} + \frac{b}{2} s^{a_{mat}+2} f_{0,t-a_{mat}-1} + \frac{b}{2} s^{a_{mat}+3} f_{0,t-a_{mat}-2} \cdots \quad (10)$$

This is a discrete form of the Lotka renewal equation (Lotka, 1907; Goodman, 1982), which has a solution for a constant rate of increase by replacing $f_{0,t}$ with λ^t. Dividing through by λ^t yields:

$$1 = \frac{b}{2} s^{a_{mat}+1} \lambda^{-a_{mat}} + \frac{b}{2} s^{a_{mat}+2} \lambda^{-a_{mat}-1} + \frac{b}{2} s^{a_{mat}+3} \lambda^{-a_{mat}-2} \cdots = \frac{b s^{a_{mat}+1} \lambda^{-a_{mat}}}{2(1 - s\lambda^{-1})} \quad (11)$$

Note that if the rate of increase and two of the three life history parameters are known, the third life history parameter is determined. Consequently, only three of the four parameters can be assigned values and the fourth will then be determined by the other three. For these analyses, we chose values for λ because the inference included a healthy population model with fixed growth rate range. In the Bayesian analysis, we chose to put an uninformative prior distribution on λ (i.e., a uniform distribution) because we were interested in the probability of the future increase or decline of this population. Furthermore, we assigned prior distributions to age at sexual maturity and survival rate; therefore, birth rate was a derived parameter.

The quantities of interest are the maximum rates of increase (λ_0) of the population, which under compensatory density-dependence, is the annual growth rate near zero population size. For a population that is doing well and has the capacity to increase, λ_0 should be greater than 1.0. However, if the population is in a state of decline, λ_0 may well be less than 1.0. To allow for both possibilities, the prior distribution for the maximum annual growth rate, λ_0, was specified to be a uniform distribution between 0.94 and 1.031 in order to provide a broad, uninformative prior distribution for this parameter.

It is thought that the maximum annual increase for an odontocete cetacean with a life history such as a beluga whale is unlikely to be much greater than about 1.04 or 4% per year (Reilly and Barlow, 1986; Wade, 1998, 2009). The BB population has increased at an estimated rate of 4.8% per year (95% CL: 2.1%–7.5%) (Lowry et al., 2008). Therefore, the value of 1.06 (a 6% increase per year) could be considered a reasonable upper bound for this parameter. However, carcass counts and calving rate data, described in more detail below, provide maximum possible survival and birth rates which because of the functional relationship of these parameters effectively reduces the upper limit for λ_0 to 1.031.

Log-linear regression of the CIBW abundance estimates for 1999–2014 indicate an annual rate of decline of -1.3% (SE = 0.008) (Shelden et al.[4]); consequently, the lower bound of 0.94 (representing a 6% decline per year or the slope of the recent trend minus more than five times the SE of the slope) was set to a value thought to be low enough to capture any possible outcome from the analysis. The results for each model scenario were examined to ensure that the data did not support any greater rate of increase or decline. Model scenarios were rerun with a broader prior distribution where support was indicated.

If the population is healthy and growing, such as the BB population, we would expect the value of λ_0 to fall between 1.02 and 1.031, (i.e., annual growth of 2% to 3.1%) and by definition, the value of λ at carrying capacity, what we call λ_k, for a healthy population would be 1.0 (i.e., no annual growth or decline), causing the population size to stabilize and reach equilibrium near the value K. Each of the alternative scenarios was modeled as a modification to this healthy population model. To account for several different survival or fecundity models, given that λ_0 was allowed to be less than 1.0 in some scenarios, we devise a healthy population growth rate for a small population, λ_{H0}, with a prior distribution between 1.02 or λ_0 (whichever was larger) and 1.031, which spanned the range of what would be the expected maximum rate of increase for a beluga whale population.

The model scenario with no additional mortality (healthy), specified a prior distribution for λ_0 of a uniform distribution between 1.02 and 1.031. In this case, λ_0 and λ_{H0} are equal, with the assumption that the population will increase if below K. If a scenario includes reduced survival and/or fecundity λ_0 is less than λ_{H0} and the

[4]Shelden, K. E. W., C. L. Sims, L. Vate Brattström, K. T. Goetz, and R. C. Hobbs. 2015. Aerial surveys of beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2014. AFSC Proc. Rep. 2015-03, 55 p. Available at http://www.afsc.noaa.gov/Publications/ProcRpt/PR2015-03.pdf accessed 8 Sept. 2015.

difference of λ_{H0} -λ_0 determined the magnitude of the reduction of fecundity and/or survival under the alternative scenario. The values of λ_{H0} and λ_K = 1 at $N = K$ determine the density-dependent drop in the population growth rate. For example, if λ_{H0} is 1.03 and λ_0 is 0.99, density dependent change in the growth rate is -0.03, whereas, the change resulting from reduced survival and/or fecundity is -0.04 at both $N = 0$ and $N = K$.

Survival Rate

A uniform prior distribution was set for s_0, the maximum population level survival rate, when the population is near zero and where (under the standard assumption of density dependence) the population is assumed to be healthy and growing at a maximal rate. A range (0.962–0.975) was specified for this distribution to make it an uninformative prior distribution, while avoiding values that were not possible for the prior range of λ_{H0} and the range of birth rates.

The upper value for the prior distribution was calculated by estimating the maximum survival rate that could be achieved by the CIBW population. A minimum annual mortality rate was estimated from annual summaries of beach-cast and floating CIBW carcasses reported to the NMFS Alaska Regional Office (e.g., Vos and Shelden, 2005; NMFS[3]). From 1999 through 2014, a total of 148 carcasses were found, of which 10 were attributed to killer whale predation and, as three of the deaths were lactating females, an additional 3 calves were thought to have died though carcasses were not found (NMFS[3]). The remaining 138 carcasses result in an average of 8.6 documented deaths per year over the 16-year timespan (Allen and Angliss, 2013), or 2.5% per year (SE = 0.3%) from a population size that has averaged 346 animals during those years. The lower value for the prior distribution was set to the minimum value that would allow a growth rate of 1.02 with a birth rate of 0.20 per year to encompass the range of possible values for the healthy population growth rate in Cook Inlet.

The value of s_K was set to $s_0 - \frac{\lambda_{H_0} - 1}{2}$ to partition the density-dependent effect approximately evenly between the survival and birth rate. The priors for the parameters of the environmental variation were determined from the variation in the annual counts of beach-cast carcasses. The value for σ was drawn from uniform [0.005, 0.01], the square root of the variance of the annual observed mortality rates (carcass count/average population size) less the variance of the demographic stochasticity. The value for ρ was chosen from a uniform [0.5, 0.8].

Age of Maturity

The prior distribution for the age of maturity (a_{mat}), or the age at first possible birth was set at 9 GLGs based on an average age of first pregnancy of 8.25 GLGs which would result in a first birth at age 9 GLGs (Table 2).

Birth Rate

With the population rate of increase, survival rate, and age of maturity specified we solve Equation 11 for birth rate (b) as a function of the other parameters to get Equation 12. Equation 11 was solved with extreme values of b and s to identify the limits for survival and intrinsic rate of increase that will allow b to fall into the specified ranges (Brandon and Wade, 2006). Equation 12 is then solved for b given s, a_{mat}, and λ:

$$b = \frac{2(1 - s\lambda^{-1})}{s^{a_{mat}+1}\lambda^{-a_{mat}}} \qquad (12)$$

This equation was used to determine the annual probability of giving birth when the population was small (b_0) or large (b_K), using the values for λ_{H0} and s_0 or $\lambda_K = 1$ and s_K, respectively. The values for s_0 and s_K were constrained so that b_0 and b_K fell into the biologically reasonable range for these variables of [0.05, 0.20] and [0.0, b_0], respectively. Ranges were derived from the data on pregnancy rates and birth interval from wild beluga populations (Table 2) and a calving rate study conducted in Cook Inlet (Hobbs et al., 2015b), with 0.05 set lower than the lowest value of 0.13 found in the literature to allow for the possibility of poorer fecundity in Cook Inlet and the value 0.20 set at nearly twice the value estimated in Cook Inlet to allow for the possibility that the time period in which the calving rate was estimated was unusually low and to also allow for potential bias in the index itself. The value for σ_b is set to 33 so that variation in annual birth rate had an equivalent effect on the variation in annual growth as on the variation in survival. The same correlated random series was used for both survival and birth rates.

Density Dependence

The prior distribution for carrying capacity (K), the population size that the population would reach if there is no reduction in birth rate or survival rate except due to density dependence and there is no environmental variation, was a uniform distribution U[811, 2056] based on a log-normal 95% confidence interval for an estimated 1,293 beluga whales from an aerial survey conducted in August 1979 by the ADFG (Calkins[1]; Hobbs and Shelden[5]). No error was calculated for this estimate; thus, we have assumed that it was no more accurate than the 1994 estimate, and we have applied the CV from the 1994 aerial survey estimate.

While this is the best available estimate of population size before the 1990's, it potentially represents a population that was depleted to an unknown degree by poorly documented and undocumented removals in earlier years of the 20th century (Mahoney and Shelden, 2000). The prior distribution on K represents the uncertainty in the estimate from 1979. For hypoth-

[5]Hobbs, R. C., and K. E. W. Shelden. 2008. Supplemental status review and extinction assessment of Cook Inlet belugas (*Delphinapterus leucas*). AFSC Processed Rep. 2008-08, 76 p. Available at http://www.afsc.noaa.gov/Publications/ProcRpt/PR2008-08.pdf, accessed 17 Sept. 2015.

esis H8 we also consider a change in K over time. For these scenarios, we reduce K by a constant amount each year between 1979 and 1999, the values for K_{1999} in 1999 are drawn from a uniform [100, 800]. Carrying capacity continues at a constant level after 1999.

The parameter z determines the maximum net production level (MNPL; the population size where growth in numbers is greatest) as a fraction of K and determines the shape of the growth curve of the population (Taylor and DeMaster, 1993). MNPL has not been determined for Cook Inlet or any other beluga whale population, consequently we adopted a range considered reasonable for cetaceans of 50–80% (MNPL 650 to 1,040 for K = 1,300). MNPL/K is drawn from U[0.5, 0.8], then the value of z is determined by solving $\frac{1}{z+1} = \left(\frac{MNPL}{K}\right)^z$ iteratively for z. This modeling effort was focused on the behavior of the population at sizes at or below the current population size, which is well below these values of K and MNPL. Therefore, the specific values of K and MNPL will have little or minimal influence on the results.

Hunt Mortality

The prior distribution for the number of whales killed in the hunt was handled differently for two time periods. The total number of whales killed each year were poorly documented before 1994 (Mahoney and Shelden, 2000). Reported landings averaged 10 per year for the years 1987–89 and 1991–93 when a partial survey of Native hunters was conducted (Stanek, 1994). But only in 1993 was there an effort to estimate the complete removals (26 landed beluga whales). No independent study of struck and lost rates was conducted during the Cook Inlet hunt.

Struck and lost numbers reported by hunters during 1979–93 averaged 25% of the reported landings, resulting in an average of 12.5 whales reported killed in those years. In 1993 the estimated kill was 32.5 whales. Therefore, to allow for the uncertainty during this time period, the prior distribution for the number of animals killed each year for the years 1979–93 ($H_{79\text{-}93}$) was specified as a uniform distribution from 10 to 40 whales to span the range of possible take levels.

NMFS first documented the entire take (landings, and struck and lost) by the subsistence hunt starting in 1994 (Mahoney and Shelden, 2000), so the data for years 1994–98 are believed to be accurate. Hunting dramatically declined starting in 1999 with the moratorium on the hunt and with subsequent harvest management plans, and recorded landings and struck and lost whales from the hunt are thought to be accurate for the years 1999–2014 (NMFS[3]) (Table 1). Therefore, the prior distributions for total kill (landings plus struck and lost) in the years 1994–2014 were fixed at the reported values. In years when more than one value was reported, or a range was reported, the total killed in the hunt was drawn from a uniform distribution with limits at the smallest and largest value (see Table 1, i.e., 1995 U[68,74]; 1996 U[98,147]; 1997 U[65,75]).

The youngest animal documented in the hunt was 4 GLGs (Mahoney and Shelden, 2000), so the first immature age vulnerable to the hunt was set to age 4. Although the hunters are thought to have a preference for taking large white adults, some gray immature beluga were also taken in the hunt. A review of hunted whales listed in Table 2 in Mahoney and Shelden (2000:131) shows 33 individuals for which age or length was known and sex determined, 7 of which were immature (i.e., smaller than 340 cm, not pregnant or lactating, and/or younger than 9, with the youngest at 4), of these immature whales, four were females.

While 33 is a relatively small sample of the more than 250 whales killed in the hunt between 1994 and 1998, it does provide a basis for an informed prior for the fraction of the hunt that was immature animals. The standard Beta distribution, Beta(α, β), is considered the likelihood distribution for the probability of success estimated from binomial data with α-1, successes and β-1, failures (Johnson and Kotz, 1970). The distribution for the probability that an individual taken in the hunt is immature is then Beta(8, 27), with the parameters derived from the values 7 immature captures (successes) and 26 mature animals (failures) recorded in the hunt data. Therefore, the informed prior distribution for the probability that an animal taken in the hunt was an immature, $Pr(Hunt\ Immature)$, was drawn from Beta(8, 27), truncated at the 2.5th and 97.5th percentiles.

For mature whales, the hunt was biased towards males. Of the 26 mature whales for which sex was determined, 16 were males and 10 were females. The male bias may be due to the fact that when a calf was seen closely associated with a whale (presumably the mother), the hunters would break off pursuit, creating a bias toward taking males (Huntington, 2000). The Beta distribution was also applied; therefore, the informed prior distribution for sex-bias of mature belugas in the hunt, $Pr(Hunt\ Male)$, the probability that a mature animal taken in the hunt was a male, was drawn from a standard Beta distribution, Beta(17, 11), truncated at the 2.5th and 97.5th percentiles.

Modifications to Birth and Survival Rates

To account for the observed growth rate of the population, we compared the effects of four different survival factors, each of which is formulated as a modification of the survival rate, S_c, $S_{p,t}$, $S_{e,t}$, and $S_{g,t}$, and one modification of the birth rate, B_c. Of these, only $S_{p,t}$, can be parameterized from data for the Cook Inlet beluga population and is either equal to 1.0 or the value determined by the parameters. For the others, we use the λ_0, (S_x S_p s_0) and b_0 in equation (11), solving iteratively for S_x, where S_x is the product of S_c, E($S_{e,t}$), and E($S_{g,t}$). Note that these modifications do not include

density dependence so it was unnecessary to solve using $N = K$, s_k and b_k. E(X) indicates the expected value of a stochastic process X. S_p is the value of $S_{p,t}$ when the population size is 350 belugas.

When more than one modification was used in a model scenario, the value for S_x is partitioned into survival effects which multiplied together to equal S_x. This was done using random partitions between zero and one that sum to one as exponents of S_x. For example, if 3 partitions are needed two random numbers between 0 and 1 are drawn and then sorted into order with 0 and 1. The first partition is equal to the value of the lower number, the second is the difference between the two random numbers, and the third is the difference between the larger random number and 1, so that product of the three partial powers of S_x is S_x.

If the model scenario includes killer whale predation, which has fixed parameters, this has been accounted for and S_x is partitioned to account for the other survival effects if it is less than 1. In a model scenario with the per capita effect, both survival rate and birth were modified, so first the partitioning described above is completed then S_c is raised to the power 0.5 and then $B_c = \frac{1-s_0}{1-s_0 S_c}$ so the decrease in birth rate is proportional to the increase in mortality.

Per Capita Survival and Fecundity Effects

When these survival and fecundity effects are included in a model scenario they are used together. The values for B_c and S_c are based on the necessary partitioning of the value of S_x. Both B_c and S_c are constrained to be greater than zero and less than or equal to 1. These are intended to model effects that impact the population on a per capita basis such as reduced frequency of foraging events resulting in chronic under nutrition, or significant contaminant loads resulting in poorer survival and fecundity.

Killer Whale Predation Mortality

Killer whale predation was modeled as a constant expected number of individuals. C_s is estimated as the average number of observed deaths from killer whales during the time period 1999–2014. The data available on killer whale predation in Cook Inlet are based on recovered carcasses, and determining the actual number of deaths depends on knowing the discovery rate of carcasses. To get around this problem, C_s is calculated from the expected number of total deaths (the total mortality rate in the population model times the population size), and from the proportion of carcasses determined to be the result of killer whale predation.

During the period 1985–2002, known beluga whale deaths resulting from killer whales averaged about one per year (Shelden et al., 2003). More complete records are available for the period between 1999 and 2014, when 148 beluga carcasses were discovered and of these 10 were determined to be the result of killer whale predation (NMFS[3]), or 6.8% of all observed carcasses. Therefore, if we assume that 6.8% of all deaths between 1999 and 2014 occurred from killer whale predation, we can estimate the number of predation deaths as C_s = (0.068) (1-s_{346}) (346) where, s_{346} is the density dependent survival rate at N = 346, which was the average population size during the period 1999–2014.

These numbers may be low relative to actual deaths because belugas that are nearly or entirely consumed will not be recovered; indeed, three of the carcasses were lactating females but no calf carcasses were recovered suggesting that the calves were consumed. The parameter C_p represents a scaler to allow for decreasing or increasing the level of killer whale predation in the population model (e.g., a value of 2 means that twice as many predation deaths occurred than were observed from 1999 to 2014). Note that when $C_p = 0$, there is no mortality from predation as $S_{p,t} = 1$. The value of C_p was set to either 0.0 (no predation), 1.0 (predation equal to the number estimated from carcass data collected from 1999 to 2014), or 2.0 (predation equal to twice the number estimated from carcass data such as associated calves or carcasses that were entirely consumed).

Catastrophes (Unusual Mortality Events)

No population-wide mortality event has been documented for Cook Inlet belugas, and the events that we are considering here, such a disease outbreaks, oil spills, volcanic eruptions, or failure of Pacific salmon runs, are infrequent. Examples are available for other marine mammal populations, such as recent disease outbreaks[6] in bottlenose dolphins, *Tursiops truncatus*, on the east coast of the United States and in ice associated seals, *Phoca* spp., in the Arctic waters of Alaska.

Oil spills, such as the Exxon Valdez in Prince William Sound, Alaska, and recently the Deep Water Horizon spill in the Gulf of Mexico, have resulted in deaths of a number of species of marine mammals (Matkin et al., 2008; Schwacke et al., 2014). Between 1976 and 2004, nine documented major oil spills occurred in Cook Inlet, ranging in volume from 5,700 gallons to 395,640 gallons.[7] In addition, oil from the Exxon Valdez spill entered Cook Inlet[8], resulting in an average of one spill per three years.

There are seven known volcanoes adjacent to Cook Inlet, four of which are sufficiently active to warrant monitoring by the Alaska Volcano Observatory (Miller et al., 1998). In addition,

[6]An unusual mortality event is defined under the Marine Mammal Protection Act as "a stranding that is unexpected; involves a significant die-off of any marine mammal population; and demands immediate response." See http://www.nmfs.noaa.gov/pr/health/mmume/ accessed 14 May 2014.

[7]Alaska Department of Environmental Conservation. 2011. Major oil spills to coastal waters. Spill Prevention and Response. Division of Water. Available at http://www.dec.state.ak.us/water/wqsar/index.htm accessed 19 Mar. 2014.

[8]Map of the Exxon Valdez Oil Spill, Exxon Valdez Oil Spill Trusties Council website http://www.evostc.state.ak.us/index.cfm?FA=facts.map, accessed 19 Mar. 2014.

there are a number of volcanos south and west of Cook Inlet that could produce significant ash falls in Cook Inlet. While eruptions are infrequent, they can pose a substantial hazard when they occur.

Finally, anadromous species, such as Pacific salmon and eulachon, *Thaleichthys pacificus*, represent a concentrated feeding opportunity that the beluga population may depend on as an important component of their annual nutrition. While individual fish runs are known to vary from year to year, a coincidental failure of several runs in one year could have a substantial impact on beluga survival and reproduction. For example, other marine mammal populations, such as the southern resident killer whale population, have shown reduced survival and fecundity rates in years in which salmon returns to the Frazer River, B.C., Can., are low (Ford et al., 2010; Ward et al., 2009).

For catastrophic events, the expected or average annual survival rate E(S_e) has been set above for each population run either in the partitioning of additional survival effects or directly depending on the model scenario. The value of E(S_e) = (1-M_e P_{Me}). To determine the mortality rate per event, M_e, we use a broad prior with M_e drawn from U[0.10, 0.50] for each population run. The frequency of events, P_{Me}, is then calculated as $(1\text{-}S_e)/M_e$ for that run. The values for M_e and P_{Me} remained fixed through each population run which resulted in an expected or average annual unusual mortality rate of $(1\text{-}S_e)$ for the population run.

Group Mortality

The group size G_t is drawn at random from the distribution of groups observed in Cook Inlet during aerial surveys from 1994 to 2014, truncated at the current population size (Fig. 2). Groups within 5 km of each other are treated as one. Note that for the current population size, the average observed group size represented about 20% of the total population (Fig. 3).

An example of one type of group mortality event that was observed for the time period was a stranding of 46 animals in 2003 in which 5 animals died (Vos and Shelden, 2005), representing a group mortality rate for the event of 5/46 = 0.11. Under the assumption that all group strandings were observed for the years 1994–2014, the probability of a group mortality event in this example would then be 1/21 = 0.05. This is but one example and not the only possibility for a group mortality event. The expected or average annual survival rate E(S_g) has been set above for each population run either in the partitioning of additional survival effects or directly depending on the model scenario. Thus, we specified a broad prior distribution for the group mortality rate, M_g, of U[(1-S_g)/0.20, 1.0], with the lower limit determined by the expected mortality rate if an event occurred every year and affected 20% of the population. A value for M_g was drawn for each population run then the value for P_g is set to (1-S_g)/(M_g*0.20) for that run so that the expected mortality rate for the population is (1-S_g).

Population Size in 1979

To set up the initial population size and age structure in 1979 (N_{1979}), N_{1979} was drawn from a uniform distribution ranging from 800 to K belugas. The age structure for each sex was then drawn as a multinomial from N_{1979} using the probabilities from a stable age and sex distribution with the density-dependent survival rate for N_{1979}.

Statistical Methods

Likelihood Function

The parameters of the population model were estimated by fitting the model to population abundance estimates available from 1994 to 2014 and the ratios of adult males and females and immature animals observed in the subsistence hunt. Aerial surveys have been conducted each June–July from 1994 to 2014 using essentially the same data collection methods through the entire time series (Hobbs et al., 2000a, b; Hobbs et al., 2015a). The subsistence hunt was subsampled as discussed above based on 7 immature belugas, 10 mature females, and 16 mature males. The likelihood function used was

$$L_i = \left[\Pi_{t-1994}^{2014} T\left(\frac{N_{t,i}-\bar{N}_t}{\bar{N}_t CV(\bar{N}_t)}, DF10\right)\right] \left[\frac{\binom{H_j}{7}\binom{H_f}{10}\binom{H_m}{16}}{\binom{H_j+H_f+H_m}{33}}\right] T\left(\frac{\bar{\varepsilon}}{SE(\bar{\varepsilon})}, DF20\right) \quad (13)$$

where L_i is the relative likelihood of the *ith* population projection; *T(X, DF Y)* is the density of Student's *t*-distribution at X with Y degrees of freedom; $N_{t,i}$ is the population size of the *ith* projection in year t; $\bar{N}_t$ and $CV(\bar{N}_t)$ are the estimated abundance (point estimate) and associated coefficient of variation in year t; H_j is the sum of $H_{j,t}$, t = 1993 to 1998; H_f is the sum of $H_{f,t}$, t = 1993 to 1998; and H_m is the sum of $H_{m,t}$, t = 1993 to 1998. $\bar{\varepsilon}$ is the average deviation of the environmental variation from 1994 to 2014 and SE($\bar{\varepsilon}$) is the standard error for $\bar{\varepsilon}$ when $\sigma = 0.01$.

The Student's *t*-distribution was chosen as the likelihood function for the abundance estimates by comparing the fit of several different likelihood functions to the distribution of bootstrap abundance estimates that results from analysis of these survey data. The Student's *t*-distribution with 10 degrees of freedom was chosen because it provided a better fit than a Student's *t* with 5 degrees of freedom, a gamma distribution, a log-normal distribution, or a normal distribution.

Parameter Estimation

Each individual population projection was fully defined by the 18-parameter vector: λ_0, λ_{H0}, λ_k, s_0, s_K, a_{mat}, N_{1979}, K, K_{1999}, z, H_t, *Pr(Hunt Immature)*, *Pr(Hunt male)*, C_p, P_{Me}, M_e, P_g, and M_g (Table 3). Note that two of the parameters (a_{mat}, C_p) were set at fixed values for any particular model scenario. While this is a substantial

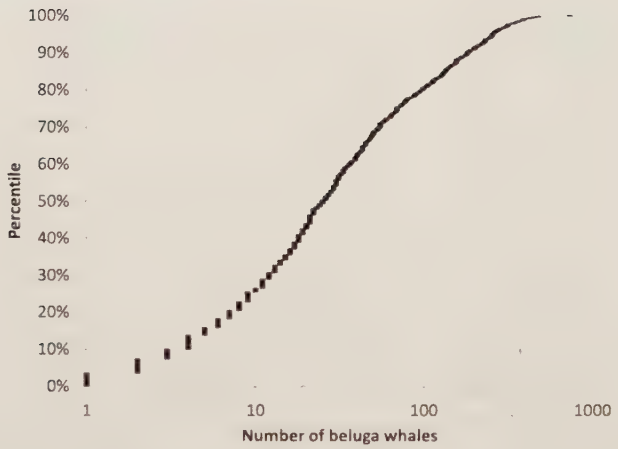


Figure 2.—Cumulative distribution of estimated group sizes for Cook Inlet beluga whale groups observed during abundance surveys, 1994–2014. The bars are the estimated group sizes from abundance surveys in June and July. For each group mortality event, a group size is chosen at random from this distribution truncated at the current population size.

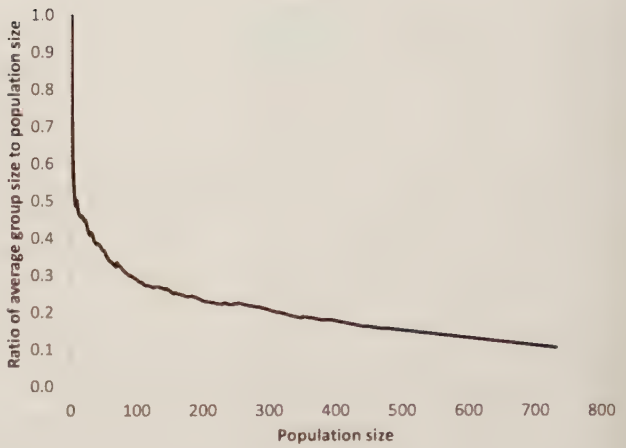


Figure 3.—Ratio of average group size to population size for Cook Inlet beluga whales when group size distribution is truncated (such that the largest possible group is the population size for groups observed during abundance surveys, 1994–2014). The average risk to animals within a group remains constant but the average risk for population size is proportional to this ratio.

Table 3.—Estimated model parameters and their prior distributions.

Parameter	Description	Prior distribution
λ_0	Annual growth multiplier (or $e^{(\text{intrinsic rate of growth})}$) when the population size approaches 0	Healthy model scenario U[1.02, 1.031]; alternative model scenarios U[0.94, 1.031]
λ_{+0}	Annual growth multiplier (or $e^{(\text{intrinsic rate of growth})}$) for healthy population size approaches 0	Healthy model scenario $\lambda_{+0} = \lambda_0$; alternative model scenarios U[1.02, 1.031] or U[λ_0, 1.031] if $\lambda_0 > 1.02$
λ_K	Annual growth multiplier when the population is at K.	1.0
s_0	Survival rate when population size is small (close to 0) and survival is unmodified.	U[0.962, 0.974]
s_K	Survival rate when population size is at K and survival is unmodified.	U[s_0 λ_K / λ_0, s_0]
a_{mat}	Age of maturity or age at which a female could first give birth	Fixed at 9 GLGs
N_{1979}	Total population size in 1979	U[800, K]
K	High density population size (derived from aerial survey results in 1979: Calkins [text footnote 1], Hobbs and Shelden [text footnote 5]	U[811, 2056]
K_{1999}	High density population after 1999 in models M, N and O	U[100, 800]
z	Shape parameter resulting in a maximum rate of population increase at MNPL (c.f. Taylor and DeMaster, 1993)	Iterative solution for z of
H_t	Total number of whales killed in the hunt in year t (includes landed and struck and lost whales)	$H_{79\text{-}93}$ U(10, 40) $H_{94\text{-}12}$ Reported values (see Table 1)
Pr(Hunt Immature)	Probability that an animal taken in the hunt was an immature whale	Beta(8, 27)
Pr(Hunt Male)	Probability that a mature animal taken in the hunt was a male	Beta(17, 11)
C_p	Constant mortality effect (killer whale predation) (can be thought of as the number of deaths per carcass)	Fixed at 0, 1, or 2 (depending on model scenario)
P_{Me}	Probability of a catastrophic mortality event occurring in a given year	Fixed at 0.0 or calculated as (1- $E(S_{e,t})$)/M_e (depending on model scenario)
M_e	Individual probability of mortality during a catastrophic mortality event	Fixed at 0.0 or U[0.10, 0.50] (depending on model scenario)
P_g	Probability of a group mortality event occurring in a given year	Fixed at 0.0, or calculated as (1- $E(S_{g,t})$)/(0.20 M_e) (depending on model scenario)
M_g	Individual probability of mortality in the affected group during a group mortality event	U[0.10, 1.0] or 0.0 (depending on model scenario)
G_t	Size of the group in which a group mortality event occurs at time t	Observed distribution of group sizes (with upper limit = N_t)

Table 4.—Other parameters and variables and their derivation, if applicable.

Parameter	Description	Derivation
N_t	Population size at time t	$\sum f_{a,t} + m_{a,t}$
$f_{a,t}$, $m_{a,t}$	Number of females and males, respectively, of age a at beginning of year t	Eq. 1
$f_{mat,t}$, $m_{mat,t}$	Number of mature females and mature males, respectively, at beginning of year t	Eq. 1
$s_{a,t}$	Probability of an individual at age a in year t surviving to age $a+1$ year $t+1$	Eq 3
b_t	Probability of a mature female giving birth to a live offspring in year t	Eq. 2
b_0	Values for fecundity when population size approaches 0	From Eq. 2, and required to be within interval 0.05 to 0.20
b_K	Values for fecundity when population size is at K.	From Eq. 2, and required to be within interval 0.00 to b_0
C_s	Constant mortality effect annual deaths depends on survival rate for each case	$0.068(1-s_{346})346$
$H_{j,t}$	Landings of immature whales in the hunt in year t	$B(H_t, Pr(Hunt\ Immature))$
$H_{m,t}$	Landings of mature male whales in the hunt in year t	$B(H_t - H_{i,t}, Pr(Hunt\ Male))$
$H_{f,t}$	Landings of mature female whales in the hunt in year t	$H_t - H_{i,t} - H_{m,t}$
NV_t	Total number of immature animals in the vulnerable age classes in year t	$\sum f_{a,t} + m_{a,t}$ for age 4 to a_{mat}
$S_{h,j,t}$	Survival rate of juveniles from hunting in year t	$1-H_{j,t}/NV_t$
$S_{h,f,t}$	Survival rate of adult females from hunting in year t	$1-H_{f,t}/f_{mat,t}$
$S_{h,m,t}$	Survival rate of adult males from hunting in year t	$1-H_{m,t}/m_{mat,t}$
S_t	Population survival rate in year t	1.0 or partition of S_x
S_c	Survival of a constant per capita impact	Eq. 6
$S_{p,t}$	Survival of a constant mortality effect such as predation by killer whales in year t	Eq. 7
$S_{e,t}$	Survival of a catastrophe, a stochastic event in year t	Eq. 8; $E(S_{e,t})$ partition of S_x
$S_{g,t}$	survival of a group mortality, a stochastic event affecting a social group in year t	Eq. 9; $E(S_{g,t})$ partition of S_x
S_x	Product of survival of modifications partitioned in to survival for individual effects S_c, $S_{p,t}$, $E(S_{e,t})$ and $E(S_{g,t})$.	Eq. 11 solved iteratively for $s_0 S_x$ with λ_0 and b_0 fixed.
B_c	Reduced fecundity of a constant per capita impact	Eq. 2, $B_c = \frac{1-S_0}{1-S_0 S_c}$
σ_b	A scaling factor for environmental variation of fecundity	Eq. 2
ε_t	A stationary correlated random environmental deviation with mean = 0 and variance = σ^2 and correlation = ρ	Eq. 2
ω_t	A stationary uncorrelated random environmental deviation with mean = 0 and variance = σ^2	Eq. 2
σ^2	Variance of environmental effect on annual survival	Eq. 2
ρ	Correlation of environmental variation	Eq. 2

number of parameters, the purpose was not to estimate posterior distributions for all of these parameters to draw inferences directly, but instead include sufficient detail in each model scenario to test the ability of particular model scenarios to reproduce the existing abundance data and determine the consequences for population projections. The time lags inherent in age-structured populations are a key element of this inference. For clarity, other derived parameters (meaning they are functions of the estimated parameters) that are referred to in the methods are listed in Table 4.

A Metropolis-Hastings Markov chain Monte Carlo (MCMC) algorithm (King et al., 2010) was used to generate samples of parameter vectors (and output quantities of interest) from the posterior distribution; these samples are then used to approximate the posterior distribution. This algorithm generates a random walk through the parameter space by selecting a test set of parameters from the neighborhood of the current parameter set, estimating the likelihood for the test parameter set, then applying a stochastic acceptance test to determine if the chain updated to the new parameters or remained at the current parameters.

All parameters were updated at once, drawn from distributions centered on each parameter value and spanning one tenth of the prior of each parameter. Where a distribution other than the uniform distribution is used as the prior, the cumulative probability was used as the uniform prior then transformed. Ranges of 0.01, 0.10, and 0.20 were also tested, but 0.05 was found to give the best performance, with higher acceptance rates similar to 0.01 but larger jumps.

For each model scenario, three chains of 10,000,000 trials were generated after an initial burn in of 6,000. Every 1,000th trial was retained to create three sets of 10,000 samples from the posterior distribution. When the algorithm repeated a parameter set, i.e. more than 1,000 trials occurred without a jump, the chain was forced to jump to the next highest likelihood point in the previous 1,500 trials and a burn in of 2,000 trials was completed before accepting the next point. This process insured that the algorithm made a thorough sampling of the posterior distribution. Inference was based on the combined sample of 30,000. We tested convergence of the three chains using the method of Brooks and Gelman (1998), which uses the ratio of the covariance matrix of the parameter sets from the individual chains to the covariance among their means to estimate the potential scale reduction factor (PSRF). Values of PSRF close to 1.0 indicate that each chain is a rep-

Table 5.—Model scenarios (Models A–O) for sources of mortality affecting recovery of Cook Inlet beluga whales. "All" indicates all of the additional mortality is attributed to a single mechanism mortality model. "Partition" indicates a random partitioning between two or more mortality models (with an exception when the constant mortality effect is included, its effect is determined by the parameter C_p and the remaining mortality is partitioned).

Model ID	Annual growth multiplier (λ_0)	Per capita survival rate and birth rate effect (S_c, B_c)	Constant mortality effect (C_p)	Catastrophic mortality (M_e, P_{Me})	Group mortality event percentage (M_g, P_g)	Change in carrying capacity 1979–99	Hypothesis
A	1.02, 1.031						H1–7
B	0.94, 1.031	All					H1–2
C	1.02, 1.031		1				H3
D	1.02, 1.031		2				H3
E	1.02, 1.031		1(year<99) 2(year≥99)				H4
F	0.94, 1.031	Partition	1				H7
G	0.94, 1.031			All			H5
H	0.94, 1.031				All		H6
I	0.94, 1.031		1	Partition			H7
J	0.94, 1.031		1		Partition		H7
K	0.94, 1.031	Partition	1	Partition			H7
L	0.94, 1.031	Partition	1		Partition		H7
M	1.02, 1.031					Yes	H8
N	1.02, 1.031		1			Yes	H8
O	0.94, 1.031	All	1			Yes	H8

resentative sample of the posterior distribution.

The population sizes for the projections from 1994 to 2164 were retained as output quantities of interest, covering the period for which we have data, 1994 to 2004, and projecting 150 years into the future. A population with one or zero individuals or only one sex was considered extinct, and its population size was set to 0 for the rest of the trajectory.

Model Scenario Comparison and Selection

Model scenarios were specified that included different prior distributions for λ_0 and different fixed values for the additional mortality factors (Table 5). A model scenario (Model A) was specified that assumed the population was healthy (or recovering) by setting the prior distribution for $\lambda_{H_0} = \lambda_0$ to U[1.02, 1.031]. All other model scenarios are modifications to this healthy population scenario with λ_{H_0} drawn from U[1.02, 1.031] and λ_0 drawn from U[0.94, 1.031] or specified by other parameters with additional mortality or reduced fecundity modeled, as described above. Model B is a scenario that included per capita mortality and fecundity factors, and had a prior distribution for λ_0 of U[0.94, 1.031]. Models C–E considered the effect of killer whale predation on an otherwise healthy population, in Model C, C_p is set to 1.0, in Model D, C_p is set to 2, and in Model E, C_p changes from 1 to 2 in 1999 so that the increase in killer whale mortality coincides with the change in Native subsistence hunting practices.

The remaining models, F–O, had a prior distribution for λ_0 of U[0.94, 1.031], and where killer whale mortality is included, C_p is set to 1. Model F accounts for the reduced growth rate with both killer whale predation and per capita effects. Models G–L account for reduced growth rates with stochastic mortality effects. Model G considers the catastrophic mortality by itself. Model H uses the group mortality alone. Model I is catastrophic mortality with killer whale mortality. Model J is group mortality with killer whale mortality. Model K partitions reduced growth among catastrophic mortality, killer whale predation, and per capita effects. Model L is similar to Model K but with group mortality instead of catastrophic mortality. Models M, N, and O are the same as Models A, C, and F, respectively, but with a value for K that declined from 1979 to 1999 and remained low after 1999.

Model scenarios were compared using the Bayes factor (Kass and Raftery, 1995; Wade, 2002), where H_{xy} represents the Bayes factor comparing model scenario x to model scenario y. If model scenarios are considered to have equal prior probability (prior to examination of the data), then the Bayes factor gives the posterior odds ratio for one model scenario compared to another (Kass and Raftery, 1995). In other words, a Bayes factor of $H_{xy} = 3$ means model scenario x is 3 times more probable, in light of the data (i.e., the abundance estimates), than model scenario y.

Kass and Raftery (1995) provide a useful scale for interpreting the Bayes factor by converting it to twice the natural logarithm of the Bayes factor. With the larger of the two posterior probabilities in the numerator (model scenario x), a value less than 2 indicates no substantial difference between the model scenarios, and values between 2 and 6 are interpreted as positive evidence for one model scenario over the other. Values between 6 and 10 are strong evidence, and values greater than 10 are very strong evidence for model scenario x over model scenario y (Kass and Raftery, 1995). We employ the harmonic mean identity to estimate the relative Bayes factor as the harmonic mean of the distribution of the log likelihoods from the MCMC sample using only data from the posterior sample. The harmonic mean is a poor estimator on its own as it is highly sensitive to the few very low likelihood samples, which the MCMC algorithm will tend to include (Kass and Raftery, 1995). To resolve this we calculated the harmonic means of each posterior data set truncated at various low likelihood values and selected the quantile at which these low likelihood samples begin to dominate the inference for some of the scenarios. Inference was then done using the truncated posterior data set. The value for comparison is then twice the difference between the log Bayes factors of the two models or, in other words, twice the difference of the log of the harmonic means. From the three separate chains, we estimated a standard error for each 2 log Bayes factor estimate. Hypothesis testing was done by comparing the Bayes factor, and examining the posterior distributions.

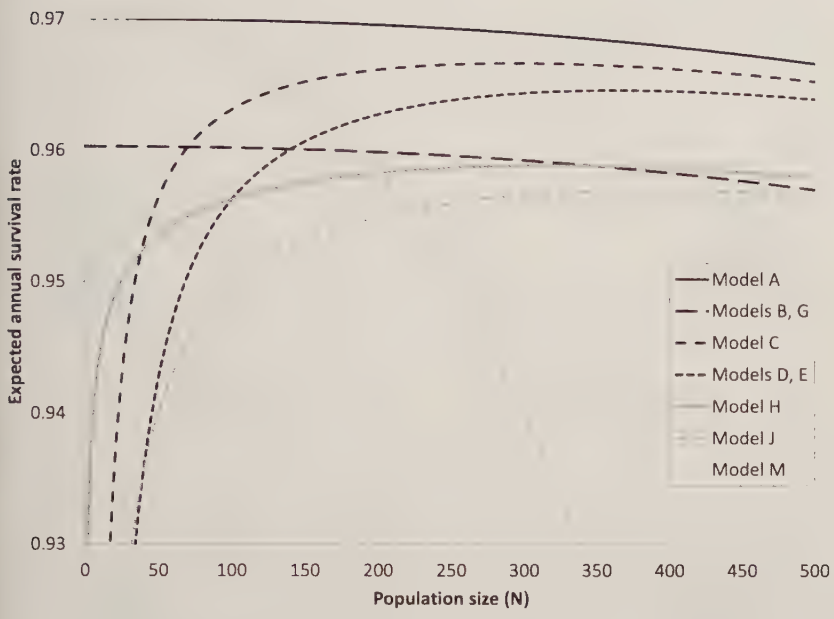


Figure 4.—Annual survival rates by population size for Cook Inlet beluga whales under different mortality models. For these examples, the density dependent survival (solid black line) is for s_0 = 97% and s_K = 94% with K = 1,300 and MNPL at 780 (z = 2.39) (Model A). With per capita mortality or catastrophic mortality events averaging 1% per annum (black long dash), the survival is reduced uniformly by 1% (Models B, G). With constant mortality added at C_p=1 (black medium dash), the survival declines quickly as the population declines below 100 animals (Model C), and for C_p =2 (black short dash), as the population declines below 200 animals (Model D, and Model E after 1999). While the group mortality events (solid gray line) results in a 1% decrease when the population is near 350 animals, survival drops off quickly as the population declines below 100 animals (Model H), and when combined with constant mortality at C_p =1 (gray medium dash), survival drops when the population is below 200 animals (Model J). In the models with reduced carrying capacity (gray short dash), the density dependence acts at lower population sizes. In this example, K is reduced to 350 belugas (Model M after 1999).

Results and Discussion

To illustrate the consequences of the different mortality effects in relation to population size, examples of expected annual survival rates by population size are given in Figure 4. Where survival rate is determined only by density dependence, survival increased as the population declined (Fig. 4, solid line), so that the highest survival rate (97% in this example) occurs as the population approaches zero.

When the catastrophic mortality effect is added, because it is independent of population size, in this example there is a 1% reduction in survival throughout the range of population sizes. When killer whale predation or group mortality effects are added to the population model, survival still increases as the population declines at moderate population sizes, but below some threshold population size, survival declines as population numbers decline (Fig. 4). This represents depensation, or an Allee effect, which is known to increase extinction risk for small populations (Courchamp et al., 1999).

Consequently, if demographic stochasticity environmental variability or mortality events pushed the population below the threshold, the population continues to decline to extinction. For example, the group mortality effect intensifies as the population declines because there are fewer groups, so each individual is more likely to be in a group that is affected. When the group mortality effect is included with the constant mortality effect of predation, the threshold effects are combined (Fig. 4, gray dashed line).

Population Model Results

The MCMC numerical integration method makes it possible to calculate a posterior distribution for any output quantity of interest. For each of the model scenarios, we calculated posterior distributions for population size in 50 and 100 years, as well as for the population growth rate over the next 20 years (2014–34). All model scenarios showed a range of outcomes (Fig. 5; Table 6), which could include a decline to extinction, an increase to K, and intermediate values between extinction and K. For the purposes of these results, we define recovery as a population size exceeding 780 whales or 60% of 1,300, the largest historical CIBW abundance estimate that is based on survey data (Calkins[1]). However, the probability of each outcome depended on the parameters of the individual model scenarios.

In the healthy population scenario (Model A, Fig. 5A) there was a 99% probability the population would increase during the next 100 years, with a median value above 1,000 by 2080 and 0% probability of extinction in 100 years. In the per capita mortality scenario (Model B, Fig. 5B), there was an over 50% probability that the population would decline (Table 6), with limited probability of recovery to 780 belugas. This contrast in outcomes was largely predicted by the distribution of population trends over the years 2014–2034, where the Model A growth rate over the next 20 years is nearly all increasing (i.e. >0.0) while Model B on average is near zero and has much of its distribution below 0.0 resulting in population decline (Fig. 5A,B; Table 6).

Models C–E include constant mortality from predation as an additional source of mortality in the healthy model scenario (Table 5; Fig. 5C–E). In all three models this resulted in a

small quantitative change such that the population was estimated to increase more slowly and take longer to recover, but, as in Model A, there was a high probability the population would increase and not go extinct, suggesting that the threshold effect was not acting on these population trajectories in most cases. The 20-year average trend (Table 6) for Models C–E, does decrease from Model A, reflecting decreased survival resulting from predation.

Model F combines the per capita mortality with the predation mortality at the observed level showing a slightly broader range of outcomes, but a 6% probability of extinction in 100 years (Fig. 5F; Table 6). Models G and H both include additional mortality as stochastic events resulting in increased uncertainty in the outcomes at 100 years, with the main difference that the threshold effect of the group mortality resulted in a greater risk of extinction (Fig. 5G, H; Table 6). The four models (I–L) are mixtures of the different mortality effects (Table 5). Including predation mortality with the catastrophic mortality, Model I results in similar uncertainty in the outcomes but shifts the range of outcomes toward increased risk of decline and extinction (Fig. 5I; Table 6), while including predation mortality with the group mortality, Model J has the highest risk of extinction of the scenarios (Fig. 5J; Table 6). Models K and L are mixtures of Models I and J with Model B (Table 5) and showed behavior more similar to Models K and L, respectively (Fig. 5K, L; Table 6). The three models with reduced carrying capacity all behaved similarly except that the threshold effect of predation and the per capita decline acting together had an extinction risk 3% in 100 years and predation alone had an extinction risk of 1% indicating that the lower carrying capacity reduced the risk of extinction compared to Models C and F.

Model Scenario Comparison with the Bayes Factor

The inference based on the natural logarithm of harmonic means of the

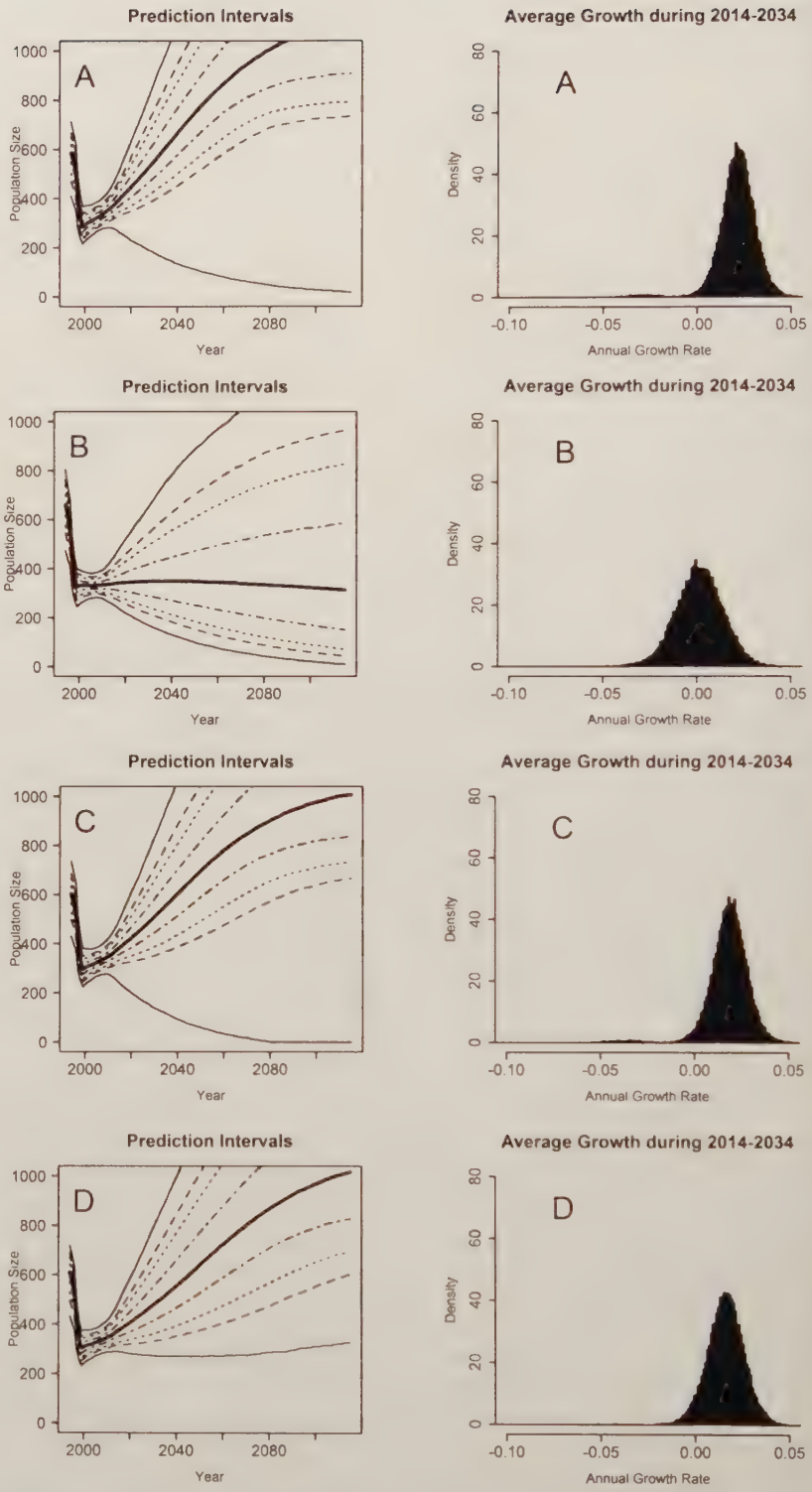


Figure 5.—Cook Inlet beluga whale population prediction intervals and posterior distributions of mean annual growth $[(N_{2034}/N_{2014})^{0.05} - 1]$ for each model scenario (Models A–O, see Table 5) from projections of the posterior sample of 30,000 trials. The heavy center line is the median (50th percentile); the dot with dash lines

Figure 5 *Continued*

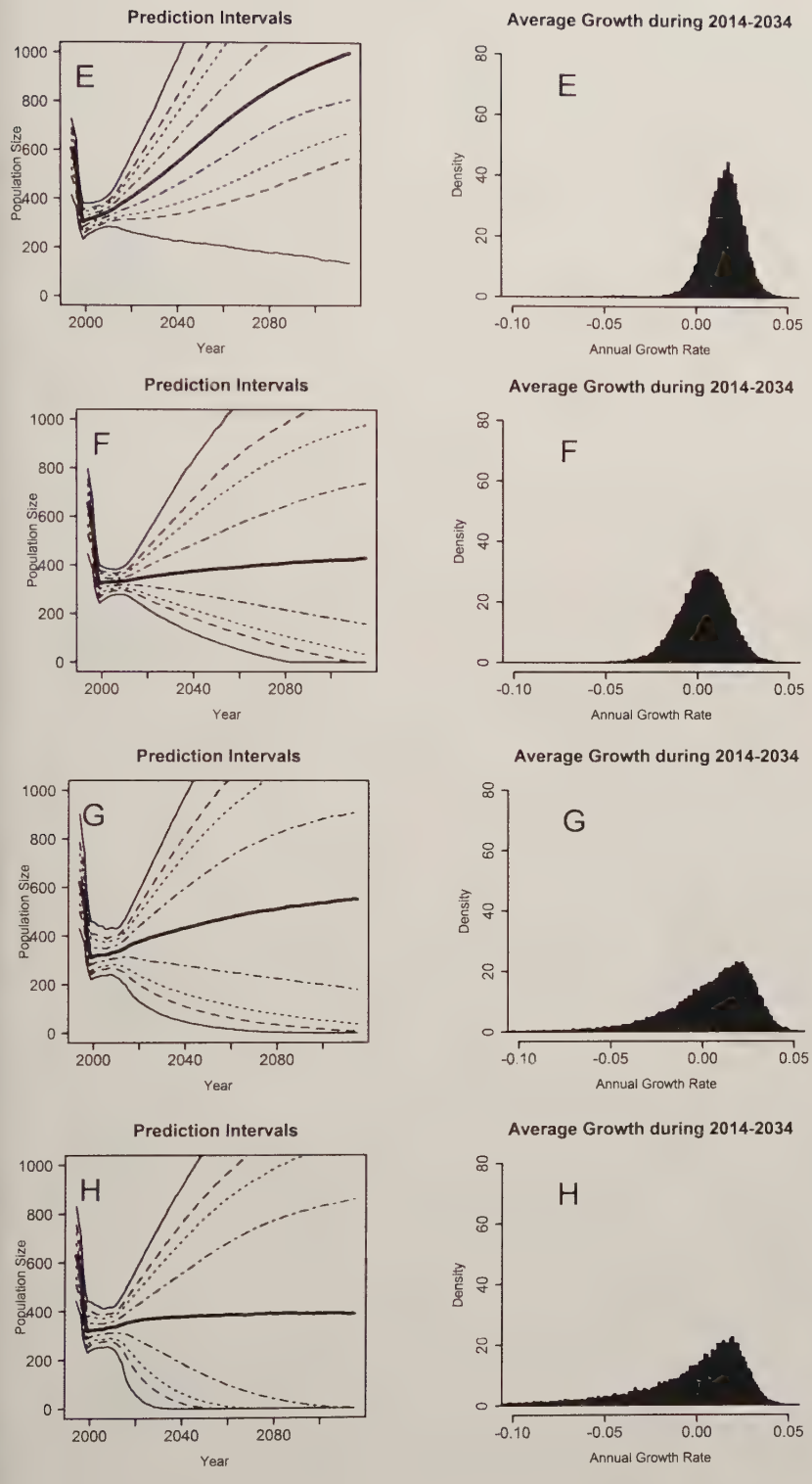


Figure 5.—Continued
on either side are the 25th and 75th percentiles; the short dashed lines are the 10th and 90th percentiles; the long dashed lines are the 5th and 95th percentiles; and the outer solid lines are the 1st and 99th percentiles. Figure 5 continues on next two pages.

posterior samples of likelihoods truncated at quantiles above 0.01 remained consistent while the inference became quite variable at quantiles below 0.01 thus, the 0.01 quantile was selected as the truncation point (Fig. 6). Samples with likelihoods less than that value of the 0.01 quantile, the lowest 300, in each data set were discarded and inference was conducted using the remaining 29,700 samples. The standard errors for the estimated 2ln(Bayes factors); were all less than 1.0 and the PSRF values were all less than 1.5 indicating that the three chains were consistent with each other and covered the posterior distribution. The alternative model scenarios with the per capita effects or the reduced carrying capacity, Models B, F, M, N, and O had substantially higher posterior probability than Model A, the healthy population scenario (Table 7). All of these alternative model scenarios had 2ln(Bayes factor) values greater than 20. Therefore, there was substantial evidence that the data supported these alternative model scenarios more than the healthy population scenario. Models D, E, H, K, and L also had higher posterior probability than Model A. The scenarios with the highest posterior probabilities were the declining carrying capacity Models M, N, and O.

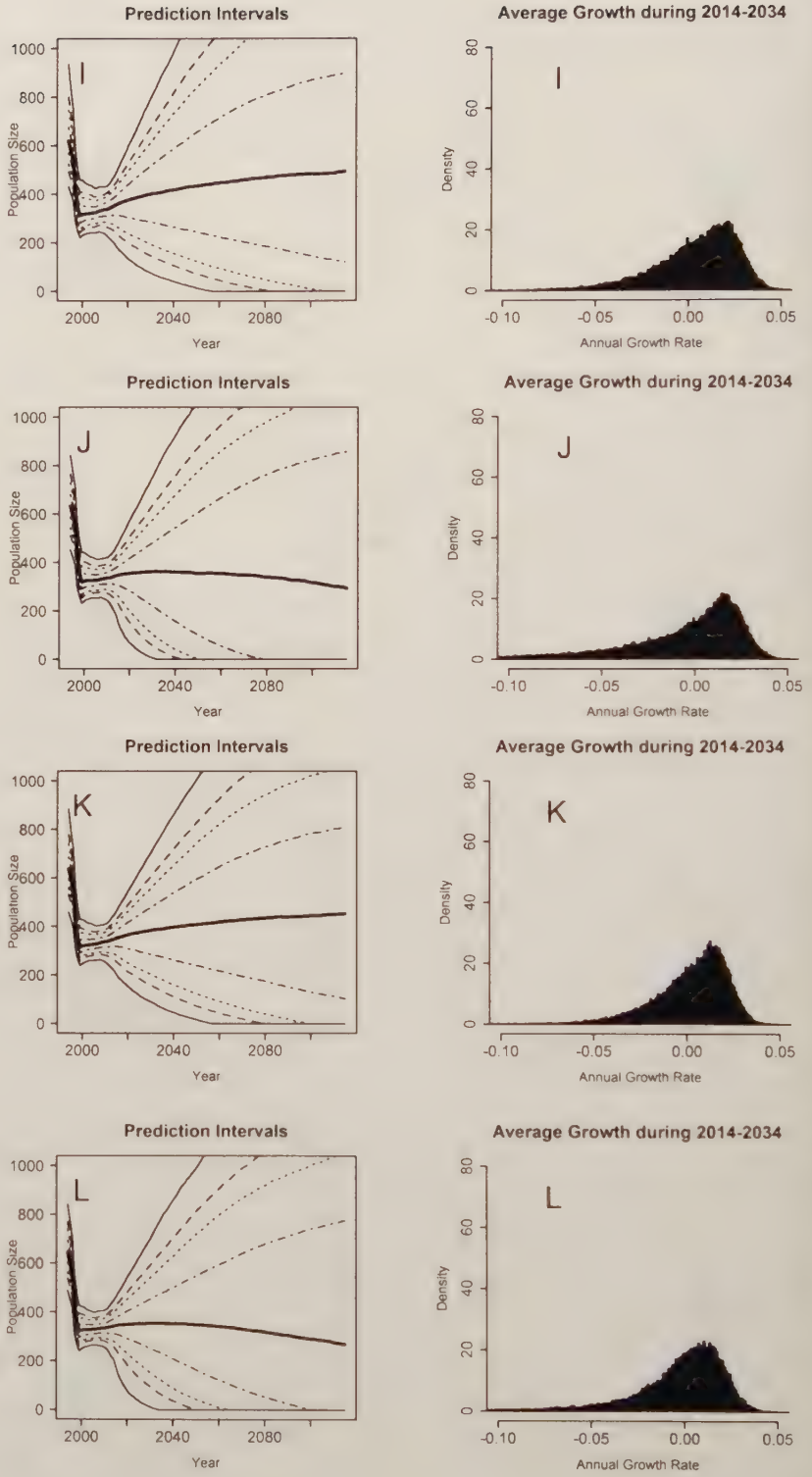
Using Models B, F, M, N, and O as the basis of comparison, we see that there is positive evidence to prefer these models over all others and, in most cases, there is strong or very strong evidence supporting these models. While the probabilities are similar, the risk of extinction is different, ranging from 0% in 100 years to 6% in 100 years, with differences resulting from the threshold effect of the predation mortality and the declining growth rates in the per capita model. Also, these models predict low probabilities of recovery to 780 belugas. Thus, a better understanding of the change in predation rates with CIBW population size, factors affecting carrying capacity and stressors impacting survival and fecundity are essential to improving the estimates of extinction risk and identifying a path to recovery.

Hypotheses Results

Hypothesis comparison and ranking using the Bayes factors provide alternative views to the same analysis. Under Hypothesis H1, the population has not yet begun to recover but it will under the status quo—there has been a delay (time lag) in recovery due to a depletion of mature females and the population will begin to increase once it rebuilds the mature female segment of the population. The data do not support this hypothesis. The Bayes factor comparison estimates Model B is 8.4×10^5 times more likely than Model A (Table 7). In other words, the proposed mechanism in Model B is supported, while a deficit of reproductive age females from the biased hunt cannot explain the lack of recovery in the population. Thus, we must conclude that the current lack of recovery is not due to time lags that will resolve in the future.

Under Hypothesis H2, the subsistence hunt was not the sole cause of the decline observed since 1994 and the population has not begun to recover because an as yet unidentified population-wide stressor (e.g., nutritional stress, disease, contaminants, noise, loss of key habitat) has caused a decrease in fecundity and/or survival, resulting in a negative growth rate. The population will not begin to recover in the future without a change in the fecundity and or survival of the population. The data support this hypothesis because Model B was 8.4×10^5 times more likely than Model A (Table 7), and there was over a 50% probability that the population will continue to decline (Table 6).

Under Hypothesis H3, the population has not begun to recover because the reduction in population size from hunting has led to it falling into a "predator pit" (a numerically constant level of predation was sustained by the population when it was >1,000 animals, but at the current population level, predation prevents recovery). The data do not support this hypothesis. Models D and E were more likely than Model A (Table 7), suggesting



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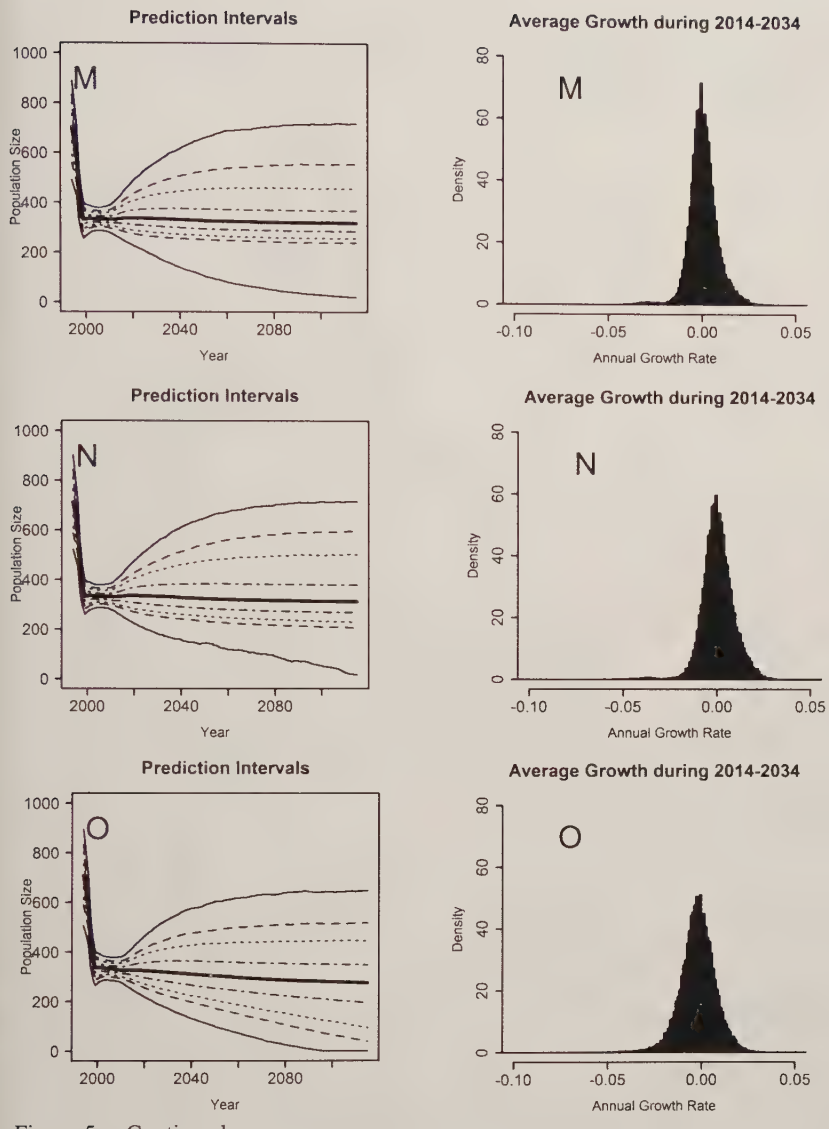

Figure 5.—Continued

Table 6.—Probability of extinction and recovery for Cook Inlet beluga whales and expected growth over the next 20 years based on model scenarios (Models A–O) for sources of mortality affecting this population. Probability of declining is the probability that $N_{2114} < N_{2014}$.

Model ID	Probability of extinction (%)		Probability of recovery (%)		Mean (SD) of annual growth % 2014–34	Probability of declining (%)
	by 2064 (50 years)	by 2114 (100 years)	by 2064 (50 years)	by 2114 (100 years)		
A	0	0	81	94	2.1(1.0)	1
B	0	0	7	14	0.1(1.3)	53
C	0	2	64	88	1.8(1.2)	2
D	1	1	50	83	1.6(1.0)	2
E	0	0	52	85	1.5(1.1)	1
F	0	6	12	25	0.3(1.3)	42
G	0	4	26	37	0.5(2.4)	37
H	9	27	22	34	-0.8(4.1)	49
I	2	13	24	35	0.3(2.4)	41
J	18	38	21	33	-1.1(4.5)	51
K	2	14	18	30	0.2(2.1)	44
L	10	29	15	27	-0.7(3.6)	54
M	0	0	0	1	0.1(0.8)	59
N	0	1	0	1	0.0(0.9)	60
O	0	3	0	0	-0.2(0.9)	71

that the mortality rates from predation are likely underestimated by carcass counts. However even when the predation mortality risk was doubled (Model D), the anticipated average growth rate over the next 20 years was reduced only by 0.3% from the average for Model A, and the probability of decline remained only 2% (Table 6).

Under Hypothesis H4, the population has not begun to recover because the level of predation from killer whales coincidentally increased around the time of the population decline (e.g., due to a prey shift by the killer whale population). The data do not provide support for this hypothesis for the same reasons stated under H3, while Model E is more likely than Model A, it does not reduce the growth rate sufficiently to prevent recovery.

Under Hypothesis H5, the population has not begun to recover because the reduction in population size from hunting and subsequent retraction in range has led to a greater proportion of the population being vulnerable to "catastrophic" mortality events such as disease outbreaks, oil or toxics spills, volcanic eruptions, or fish run failures. The results do not support this hypothesis in that Model G was 0.0027 less likely than Model A (Table 7), largely the result of the greater variability of growth from year to year.

Under Hypothesis H6, the population has not begun to recover because the reduction in population size from hunting and subsequent retraction in range has led to fewer social groups in the population, such that a greater proportion of the population is vulnerable to mortality events that affect all or a large fraction of a single social group. The results do support this hypothesis in that Model H was 110 times more likely than Model A (Table 7).

Under Hypothesis H7, the population has not begun to recover because of a combination of killer whale predation, per capita effects, and increased catastrophic or group mortality following population decline. The results support this hypothesis in that some of the model scenarios with mixed mortality effects, Models F, K, and L, were

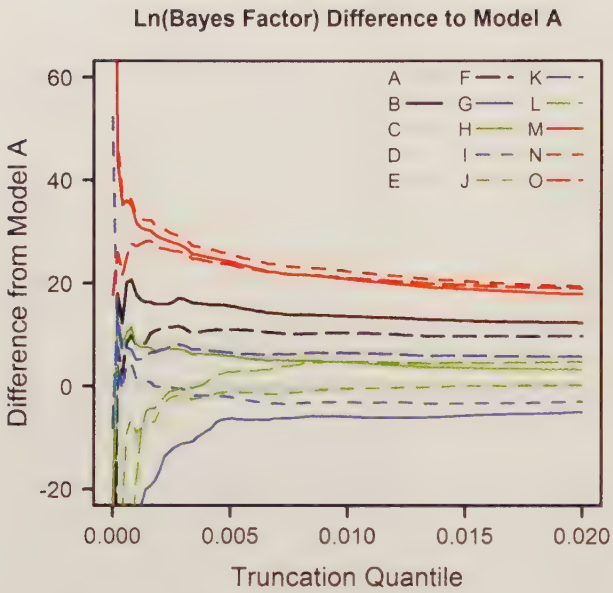

Figure 6.—Difference in ln(Bayes factor) in comparison to Model A (healthy Cook Inlet beluga whale population) when the posterior sample is truncated at various quantiles of the likelihood. Positive values indicate evidence in favor of the comparison model over Model A. Negative values indicate evidence in favor of Model A over the comparison model.

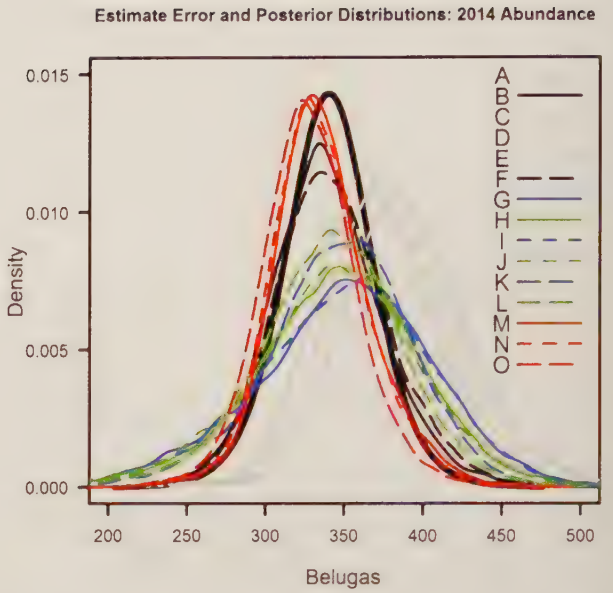

Figure 8.—The estimation error distribution for Cook Inlet beluga whale abundance in June 2014 is indicated by the heavy black line which represents a noncentral Student's *t*-distribution with mean = 340 and CV = 0.08. The posterior distributions for all models are represented by the narrow lines. The gray lines have the healthy population growth rate with or without the predation mortality.

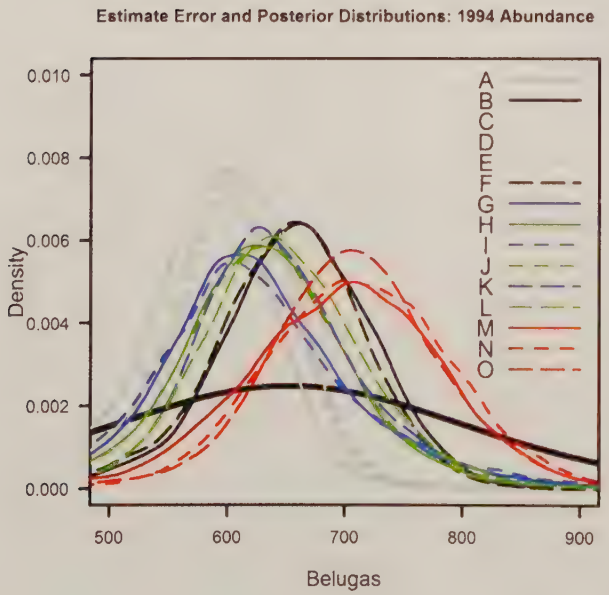

Figure 7.—The estimation error distribution and the posterior distributions for Cook Inlet beluga whale abundance in June 1994. The estimation error distribution for the abundance in June 1994 is indicated by the heavy black line, which represents a noncentral Student's *t*-distribution with mean = 653 and CV = 0.24. The posterior distributions for all model scenarios are represented by the narrow lines. The gray lines have the healthy population growth rate with or without the predation mortality. Note that while some variation occurred, all of the posterior distributions were contained well within the range of the prior.

more likely than Model A. Models I and J were less likely than Model A suggesting that the mixture with the per capita effect was key, and all of the mixed models were much less likely than Model B (Table 7).

Under Hypothesis H8, the population has not begun to recover because the carrying capacity has declined to a low level. The results support this hypotheses in that Models M, N, and O were substantially more likely than Model A (Table 7). Through hypothesis comparison, we demonstrated that several of the mortality models were more likely than the assumption of a healthy population, but this did not distinguish among the models except that the constant or predation mortality model was not sufficient by itself. The Bayes factors provided a means to rank the model scenarios and select the most likely, the per capita mortality or reduced carrying capacity with or without the threshold effect of constant or predation mortality.

Table 7.—Statistics for the posterior distributions of the Cook Inlet beluga whale expected growth rate and the Bayes factors for each model scenario compared to Model A (the healthy population scenario) or Model B (the per capita mortality model). PSRF is the potential scale reduction factor. Values of PSRF close to 1.0 indicate that each chain is a representative sample of the posterior distribution. A value of 2(ln(Bayes factor)) greater than 2.0 or less than -2.0 indicates positive evidence of one model over the other. MCMC = Metropolis-Hastings Markov chain Monte Carlo algorithm (King et al., 2010).

Model ID	Average MCMC jumps per case	PSRF	Standard error of 2X Ln Bayes factor	Bayes factor odds ratio relative to Model A	2 × Ln Bayes comparison to Model A	2 × Ln Bayes comparison to Model B
A	3.28	1.44	0.61	1.0E+00	0	-27
B	3.25	1.35	0.87	8.4E+05	27	0
C	3.28	1.20	0.18	7.3E-01	-1	-28
D	3.26	1.12	0.53	1.4E+03	14	-13
E	3.26	1.24	0.28	4.1E+02	12	-15
F	3.26	1.16	0.42	3.2E+04	21	-7
G	3.27	1.26	0.52	2.7E-03	-12	-39
H	3.28	1.13	0.45	1.1E+02	9	-18
I	3.27	1.11	0.32	4.5E-02	-6	-33
J	3.24	1.23	0.49	6.3E-01	-1	-28
K	3.27	1.40	0.82	6.5E+02	13	-14
L	3.25	1.06	0.22	1.2E+02	10	-18
M	3.23	1.13	0.40	1.1E+09	42	14
N	3.26	1.26	0.25	5.1E+09	45	17
O	3.24	1.28	0.22	1.4E+09	42	15

Posterior Distributions

There was some variability in the posterior distributions for the 1994 abundance, with modes ranging from 590 for Model A to 700 for Model O. Model scenarios with higher average growth rates had lower modes while models with negative average growth rates had higher modes (Fig. 7; Table 6). The three highest modes were Models M, N, and O which had declining carrying capacity. All of the results fell well within the sampling distribution for the 1994 abundance estimate, indicating that it was not very selective in the likelihood. Posterior distributions for the 2014 abundance distributions closely matched the sampling distribution of the 2014 abundance estimate in shape, but were somewhat lower, while the healthy population scenario and killer whale predation model scenarios favored higher values, with modes of 50 belugas greater than the 2014 abundance estimate (Fig. 8). The stochastic mortality effects broadened the distributions for Models G–J but when the per capita effect was included, Mod-

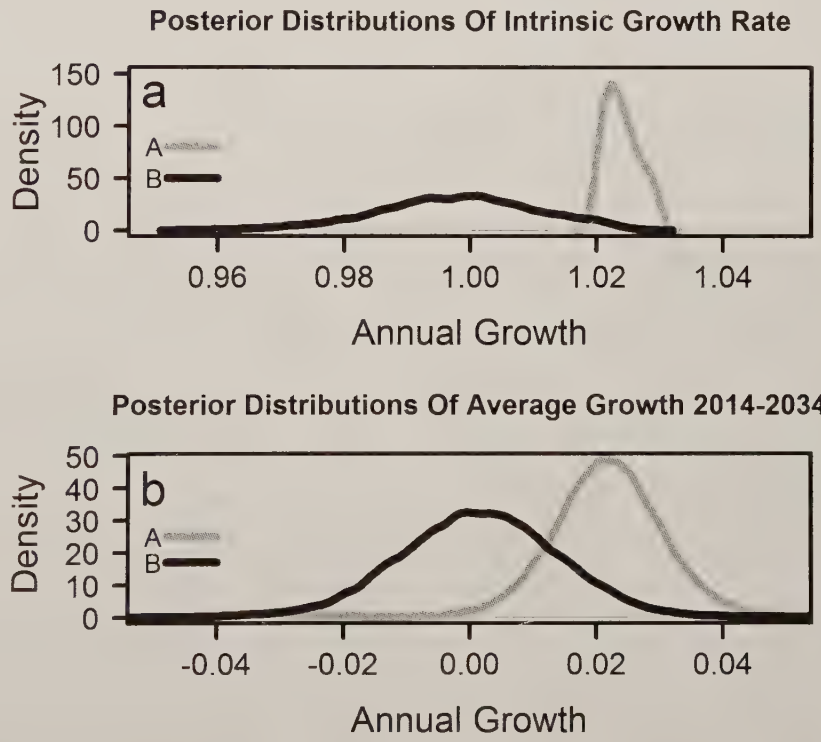

Figure 9.—Posterior distributions of a) intrinsic growth rate (λ_0) and b) of mean annual growth $[(N_{2034}/N_{2014})^{0.05} - 1]$ for Model A (healthy Cook Inlet beluga whale population, gray line) and Model B (w/per capita survival and birth rate effects, black line).

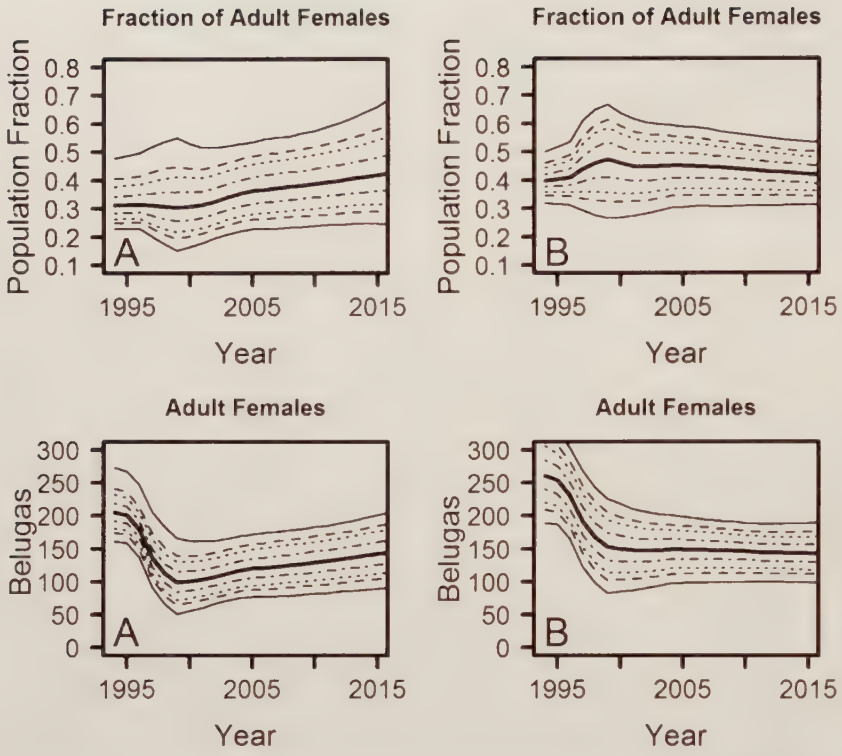

Figure 10.—Posterior distributions of fraction of adult female Cook Inlet belugas in each population trajectory and number of adult females in each population trajectory for Models A (healthy population) and B (w/ per capita survival and birth rate effects). The heavy center line is the median (50th percentile); the dot with dash lines on either side are the 25th and 75th percentiles; the short dashed lines are the 10th and 90th percentiles; the long dashed lines are the 5th and 95th percentiles; and the outer solid lines are the 1st and 99th percentiles.

els K and L, the posterior distributions were more similar to Models B and F.

As discussed above, the current lack of recovery in the population cannot be explained by a deficit of adult females caused by the subsistence hunt, as the healthy population scenario was shown to have a much poorer fit to the data. This occurs because the healthy scenario is forced (via the prior distribution) to have a positive intrinsic rate of increase, and this results in an increasing population trajectory (Fig. 9), but the trend of the abundance estimates indicates the population is not growing. Note that the posterior distribution of the intrinsic growth rate for Model A is skewed toward its lower bound indicating that the lower limit of the prior distribution was informative. The constraints on the upper limit of survival rate and birth rate limited the intrinsic growth rate to be less than 1.031, however the posterior distribution of Model A had declined to low probability so that these constraints were not informative to Model A.

A comparison of the distributions of the number of females and the fraction of females in the population trajectories for each model, shows a moderately depleted adult female fraction in the Model A trajectories during the years 1997–2003, but this is fully recovered by 2014 (Fig. 10). The results for Model B indicate that the male fraction was more strongly depleted than the female fraction but this is also resolved by 2014. In other words, while the deficit of reproductive age females is a plausible mechanism for slowing recovery, the trajectory for the numbers of adult females in Model A (Fig. 10) shows an upturn within the first few years after the end of uncontrolled hunting in 1999. This result for adult females is corroborated by the abundance trajectories for these years where the Model A trajectories begin to increase after 1999 (Fig. 11), indicating that any delay in recovery that would have occurred from a deficit of adult females would have lasted for only a few years.

One interesting outcome is that the best fit for Models A, C, D, and E occurred by estimating that a larger fraction of adult females were taken in the hunt (Fig. 12). This is a case of two sources of data conflicting. For example, Model A imposes an increasing population growth rate, which conflicts with the observed abundance trend. The growth rate can be partially offset for a few years (Fig. 11) by having a higher proportion of females taken in the hunt than actually observed, as this will slow the model population increase.

Model scenarios with a catastrophe or a group mortality effect had greater variability, such that there was a broader range of population trajectories possible. This is evident in the probabilities of recovery and extinction, and the range of growth rates from 2014 to 2034 (Fig. 5G, H; Table 6). While this variability might allow the trajectories to match the point estimates of abundance closely, it also could push the trajectory away from the abundance time series with one or two large events.

In both Models G (Fig. 13) and H (Fig. 14), the posterior distributions of the mortality rate for an event showed a preference for lower expected mortality rates (Figs. 13c, 14c). For catastrophic mortality, the histogram indicates a preference for the lower range of 10–20% mortality per event (Fig. 13a). For the group mortality, the mode is near 25% mortality per event but the distribution is quite broad (Fig. 14a); however, this is applied to a group that on average is 20% of the population and averages approximately 5% mortality at the population level. Even at 100% mortality, this only represents a 20% mortality to the pop-

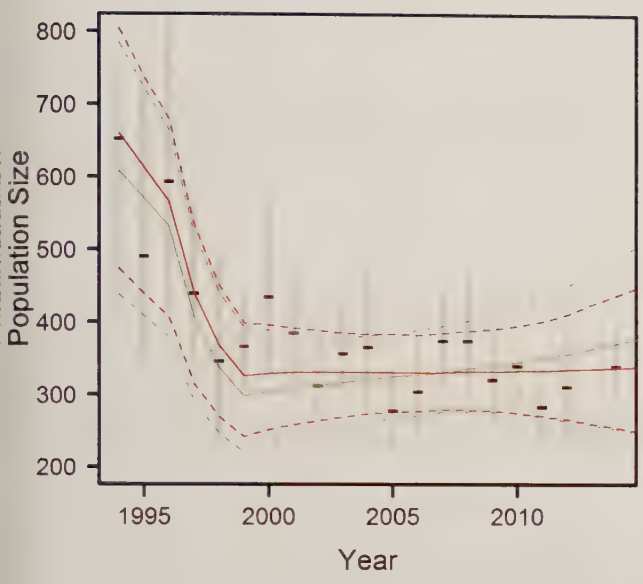

Figure 11.—Posterior distributions of Cook Inlet beluga whale population size in population trajectory for the years 1994–2014 for Model A (healthy population, green lines) and Model B (w/ per capita survival and birth rate effects, red lines) showing the median (solid), with the 1st and 99th percentiles (dashed) overlaid on the abundance point estimates (black dashes) with 95% CI (gray lines).

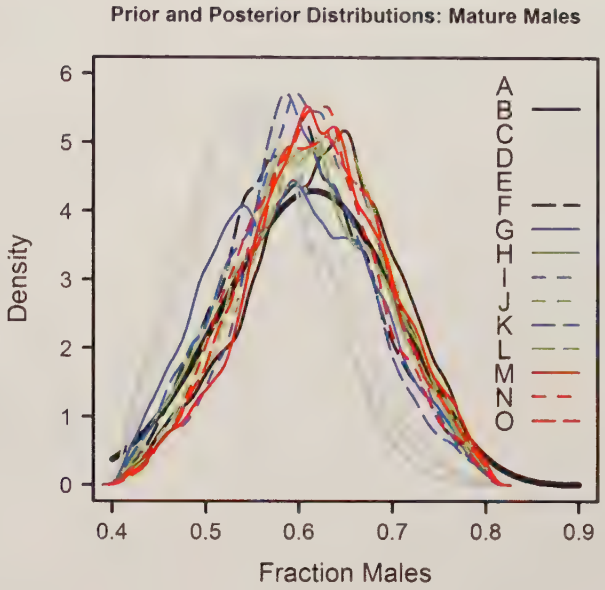

Figure 12.—Posterior distributions for the harvest fraction of male Cook Inlet beluga whales (the probability that an adult taken in the harvest is a male). The prior distribution is indicated by the heavy black line which represents a Beta distribution, Beta(17, 11). The posterior distributions for all models are represented by the narrow lines. The gray lines have the healthy population growth rate with or without the predation mortality.

ulation. Thus, the two survival models support similar ranges of mortality at the population level.

The low mortality rate for events limits the variability of the trajectories to the lowest values possible for these model scenarios. The probability of events was then determined by the change in survival rate required to achieve the change in growth rate from the healthy population scenario. For the catastrophic mortality scenario, this resulted in a fairly strong preference for lower probability of events, indicating that the selection in Model G was stronger on the event probability rather than the mortality rate (Fig. 13a, b). In contrast, for the group mortality scenario in Model H, the probability of an event was less strongly selected and resulted in a posterior distribution mode near 20% but ranging from 0% to 100% (Fig. 14b). When these are combined into the expected annual mortality, the posterior distributions have lower medians, with the median and distribution for the expected annual group mortality about twice as broadly distributed (Figs. 13c, 14c).

In general, when the predation mortality effect with $C_c = 1$ was added to the healthy population scenario (Model A vs. Model C), there was little change in the population outcomes, but it improved the fit to the data. However, when $C_c = 1$ was included in the model scenario with per capita effects on fecundity or survival (Model B vs. Model F), there was no improvement in the fit to the data, and, in fact, the fit was reduced, but it added 6% to the probabilities of extinction in 100 years. The group and catastrophic mortality scenarios, with or without predation mortality added, did not provide a good fit to the data by themselves, and received little posterior probability. However, when per capita effects were added, these scenarios improved in fit over Model A, but remained poorer fits than Model B, suggesting that of the four types of effects the per capita effects were the most likely (Table 7).

Little information is available for the model on the carrying capacity of Cook Inlet for belugas and consequently a range of posterior distributions resulted for the different model scenarios. In general, the models without either a decline in carrying capacity or a per capita effect (Models A, C–E, G–J) selected the lower values for K (Fig. 15). Models with a change in carrying capacity (Models M–O) and a per capita effect (Models B, F, K, L, O) selected higher values for K, with Model O, which included both scenarios, showing the strongest selection for high values (Fig. 15). For the three models that allowed a change in K over time, the two models that did not include a per capita effect had posterior distributions for K_{1999} that closely matched the sampling distribution for the abundance estimate in 2014 (Fig. 16). Model O (with the per capita effect and decreasing K) did select the

range of the 2014 abundance estimate, but also chose the range between 400 and 800 with nearly equal preference. This difference between the models with and without the per capita effect is also evident in the projections for the next 100 years, with the majority of cases for Models M and N showing the CIBW population remaining stable at a low level while Model O shows a significant number of declining population trajectories. None of the models selected values below 250 indicating that if the carrying capacity has declined it is not less than the current population size.

Extinction Risk and Potential for Recovery

The key purpose for this analysis was to estimate the risk of extinction and to compare potential mortality models for the endangered CIBW population. The five most likely scenarios, Models B, F, M, N, and O, are all much more likely than any of the other model scenarios, therefore, they are the preferred scenarios to estimate extinction risk. These models fit the data well because they all indicate there has been a substantial decline in the population growth rate from an expected healthy population model. In the case of Models B and F, it is through a per capita decline in fecundity or survival, whereas, in Models M, N, and O, it is through a reduction in carrying capacity. The reduction in carrying capacity in turn reduces the per capita survival and fecundity through the density dependence of the population model, as the model essentially estimates the population is close to carrying capacity.

To the five most likely models we add Model K to account for the risk of catastrophic events. While these events are known to occur, there are few data on their impact on beluga populations that could be included in the current analysis. Consequently, the likelihood of this model was not as well supported by the data used. It has, however, the highest likelihood of the models that include unusual mortality events. From these models, we estimate that the risk of extinction in 100 years is between 0% and 14% with the main uncertainty resulting from the strength of the threshold resulting from the constant mortality effect.

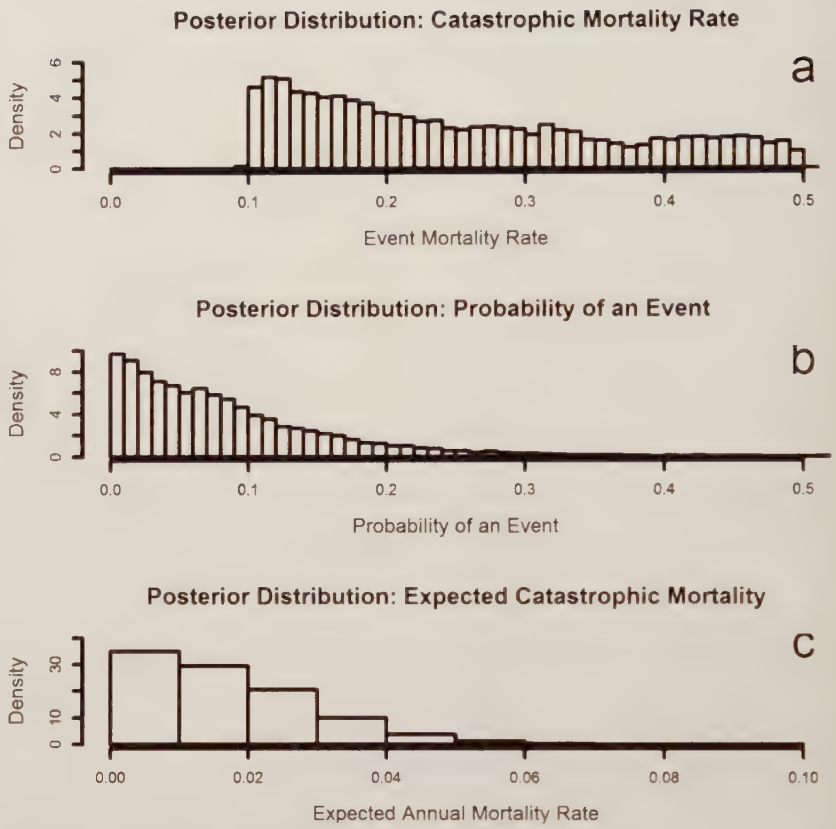

Figure 13.—Posterior distributions for Model G: a) catastrophic mortality rate (M_e) and b) probability of an event (P_{Me}), and c) the expected annual mortality rate ($M_e P_{Me}$), the product of the two. In Model G, the value of the expected annual mortality rate for the Cook Inlet beluga whale population was determined by the change in the survival rate. The value for M_e was drawn from its prior distribution, U(0.1, 0.5). The value for P_{Me} was found by dividing the expected annual mortality rate by M_e.

In 2008, Hobbs and Shelden[5] estimated the range of extinction risk to be between 1% and 27% in 100 years from a similar set of models. In our current analysis, Models B, F, and K correspond to Models a, d, and h in Hobbs and Shelden[5], respectively. There are no equivalents for Models M, N, and O in Hobbs and Shelden[5] and the current analysis includes no equivalents for their Models c, e, and g. Models a, d, and h in Hobbs and Shelden[5] had extinction risks of 1%, 12%, and 26% in 100 years, respectively; consequently, they spanned the range of extinction risks (i.e., 1–27%) in that paper, but are roughly twice the values for the corresponding models in our current analysis.

There are several reasons for these changes. First, we now have 20 abundance estimates, up from the 15 estimates used in the earlier analysis. These additional data supported the selection of annual growth rates close to zero; consequently, there is a more precise estimation of the growth rate parameter with fewer outliers that would be low and trend towards extinction. Second, the mean growth rate for Model B is 0.1%/yr with 53% of cases declining, while the corresponding Model a in Hobbs and Shelden[5] had a mean growth rate of -0.4%/yr and 62% of cases declining, which supported this slightly improved out-

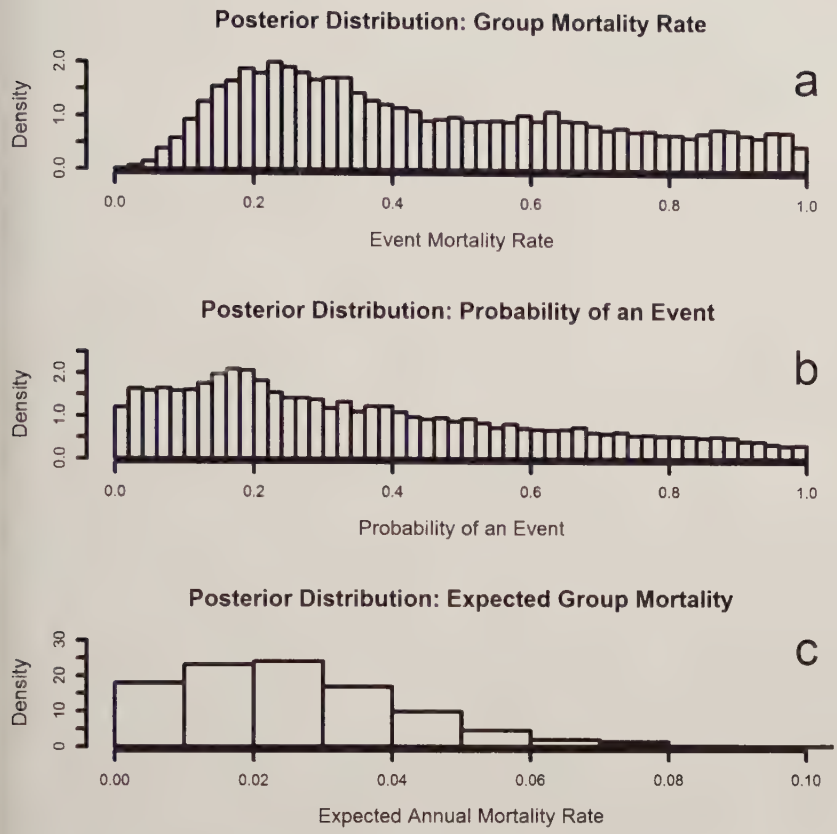

Figure 14.—Posterior distributions for Model H: a) group mortality rate (M_g), and b) probability of an event (P_g), and c) the expected annual mortality rate, (0.20 M_g P_g) where 0.20 is the average fraction of the population per group at the current abundance. In Model H, the value of the expected annual mortality rate for the Cook Inlet beluga whale population was determined by the change in the survival rate. The value for M_g was drawn from its prior distribution, U(0.1, 0.5). The value for P_g was found by dividing the expected annual mortality rate by 0.20 M_g.

look. In other words, with more data the recent trend of the population has been estimated more precisely and it has been found to be roughly stable or slowly declining. Thus, although the population is not increasing as expected, the data indicate the population is not declining precipitously, and, therefore, the probability of extinction is lower than in the previous analyses (i.e., Hobbs and Shelden[5]).

Models K and h were not identical in that in Model h of Hobbs and Shelden[5] the mortality rate was fixed at 20% and the probability of an event was fixed at 5%; consequently, the expected mortality was 1%/yr. In Model K these percentages were allowed to vary with the mortality rate chosen from between 10% and 50%, and the probability selected so that the expected mortality per year met a value selected by the model for that case. Model K also included per capita mortality and predation mortality, so the three were competing. In Model K, the average values of the probability of an event was 3.1% and the expected annual mortality from catastrophic events was 0.7%; therefore, Model K selected fewer events with a lower expected mortality rate than in Model h, which resulted in a decreased risk of extinction. Thus the effect of catastrophic mortality events was reduced in Model K compared to model h in Hobbs and Shelden[5].

The strong selection of the five model scenarios (Models B, F, M–O) indicates that the observed decline of the population is likely the result of a per capita or chronic decrease in survival or reproduction or that carrying capacity has declined. While we have provided examples of long-term habitat changes, reduction of available forage, and anthropogenic effects such as introduced toxins, there is also the possibility that the reduction in the fecundity or survival of the population is the result of reduction in population size itself.

There are many examples of population level consequences beyond the numerical effect of the removal of individuals caused by social disruption from hunting. For example, hunting elephants, *Loxodonta africana,* led to lower fecundity in several elephant populations (Poole, 1987; Gobush et al., 2008). Part of the explanation for this was the loss of "social knowledge" from the removal of matriarchs for their large tusks (McComb et al., 2001). Similarly, lower fecundity has been seen in a population of bighorn sheep, *Ovis canadensis,* where rams with larger horns were removed (Coltman et al., 2003). Heavy hunting pressure on wolves decreased the average size of social groups and led to lower natural survival for a variety of reasons (Haber, 1996). Specifically, a review of multiple studies showed that removal of breeding wolves, *Canis lupus*, led to decreased wolf packs or to the dissolution of packs, and that pup survival was higher in larger packs and was correlated with the presence of auxiliary nonbreeders (Brainerd et al., 2008). Heavy hunting pressure on cougar populations, *Puma concolor*, was correlated with increased immigration, reduced kitten survival, and reduced female population growth (Cooley et al., 2009).

At least two examples exist showing lower fecundity in cetaceans after hunting and social disruption. Fecundity was very low in Galapagos sperm whales, *Physeter macrocephalus*, after the population was severely depleted during commercial whaling, apparently due to a lack of mature males (Whitehead et al., 1997). Spinner dolphins, *Stenella longirostris*, subjected

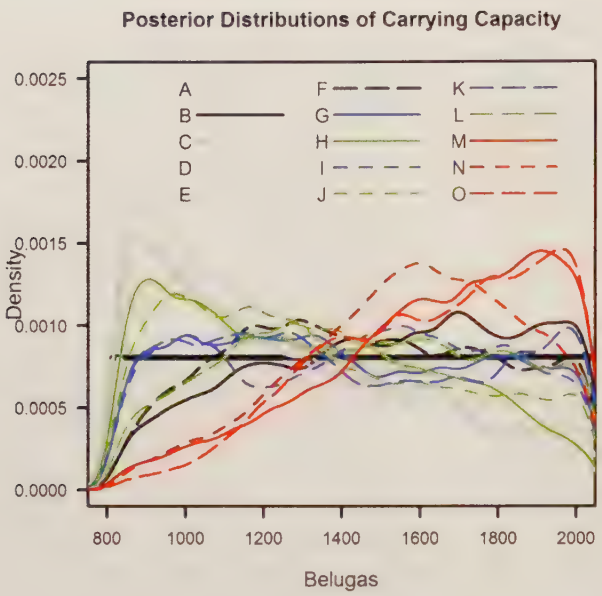

Figure 15.—Posterior distributions for K, the carrying capacity of the Cook Inlet beluga whale population. The prior distribution is indicated by the heavy black line which represents a uniform distribution, U(811, 2056). The posterior distributions for all models (A-O) are represented by the narrow lines. The gray lines have the healthy population growth rate with or without the predation mortality.

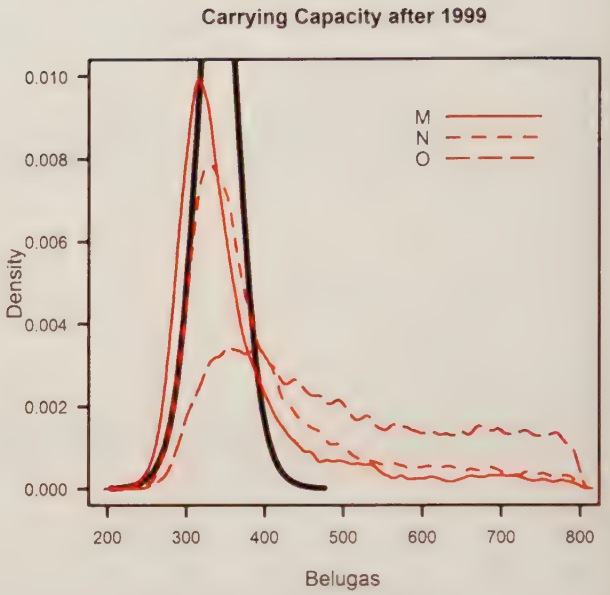

Figure 16.—Posterior distributions for K_{1999}, the carrying capacity after 1999 for the Cook Inlet beluga whale population for the three models (M, N, O) where carrying capacity declined between 1979 and 1999. The prior distribution was a uniform distribution, U(100, 800). The black line is the sampling distribution of the 2014 abundance estimate. The posterior distributions for the three models are represented by the narrow lines.

to chase and encirclement by yellowfin tuna, *Thunnus albacares*, purse seiners in the eastern tropical Pacific have experienced a decline in fecundity (Cramer et al., 2008), and this could be due to the loss of breeding males, which represent only a tiny fraction of all mature males (Perrin and Mesnick, 2003). There was also apparently lower calf survival caused by the separation of mothers and dependent calves during the chase (Archer et al., 2001). The CIBW population underwent heavy hunting pressure for at least 20 years (1979–99), which caused the population to decline from approximately 1,300 whales to about 300 whales, and the number of adult females in the population may have declined to less than 100 (Fig. 10). Social disruption from the hunt causing a decline in fecundity or survival in the population is plausible, however, we did not attempt to develop a model specific to this mechanism.

Some examples from other mammalian populations suggest that once a hunt is limited or ended, the population would rebound. Other examples, such as the loss of matriarchs in elephants, dominant breeding males in sperm whales, or optimal pack structure in wolves, suggest there is a lag of 1–2 generations, during which the population continues to decline, before the population recovers. These small population effects and the threshold effects modeled above, may act at population sizes near to the current population size, suggesting that a significantly larger population is necessary to keep the population from becoming extinct in the next 100 years.

The ultimate goal for the CIBW population is not just avoiding extinction but recovering to a sustainable size and distribution. To this end, we can draw two conclusions from the results of this modeling effort. First, if the intrinsic growth rate can be increased above 2%, then recovery is very likely. Second, one or more per capita effects are reducing survival and/or fecundity or substantial carrying capacity has been lost. While there was considerable variation in extinction risk at 100 years among the models, the assumption of an intrinsic rate of growth greater than 2% removed the risk of decline and extinction even when the threshold effect of predation mortality was included. Thus, research intended to support recovery of this population should be directed toward identifying and reversing these per capita effects. Also, a better understanding of the factors determining carrying capacity is required. The possible presence of a threshold in the growth rate resulting in an Allee effect, increases the urgency of these efforts, as reversal of the trend may become far more difficult if the population declines further. Taken as a whole, these modeling results indicate clearly that it is likely that the CIBW population will continue to decline or go extinct unless factors de-

termining its growth and survival are altered in its favor.

Acknowledgments

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Potential Natural and Anthropogenic Impediments to the Conservation and Recovery of Cook Inlet Beluga Whales, *Delphinapterus leucas*

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Introduction

Cook Inlet beluga whales, *Delphinapterus leucas*, belong to a genetically distinct and geographically isolated population (O'Corry-Crowe et al., 1997, 2002) (Fig. 1). This small and declining population was listed as endangered under the U.S. Endangered Species Act (ESA) in October 2008. It is thought that this population originally numbered close to 1,300 animals; however, the population has declined significantly from its historical abundance to approximately 312 in 2012 (Hobbs et al., 2015a). At reduced numbers and with contraction of their range (Rugh et al., 2010; Shelden et al., 2015), this population is vulnerable to losses due to natural and anthropogenic (human-caused) influences.

We present current information on potential natural and anthropogenic factors that may play a role in the decline and long-term viability of Cook Inlet (CI) beluga whales. A number of these factors identified in the Marine Mammal Protection Act (MMPA) conservation plan (NMFS[1]) and ESA status reviews (Hobbs et al.[2,3]; Hobbs and Shelden[4]) of CI belugas are of particular concern, given the lack of baseline data on their occurrence and relevance, coupled with substantial gaps in existing information on their effects on mortality and reproduction. When applicable for comparison purposes, we also consider the possible impacts of these factors on other populations of beluga whales in Bristol Bay (BB), Alaska, and the St. Lawrence Estuary (SLE), Canada.

Beluga whales in BB represent a healthy, growing population that inhabits ecological niches similar to Cook Inlet (Lowry et al., 2008). Belugas in SLE were chosen because they also represent a small, geographically- and genetically-isolated stock of beluga whales (DFO[5]). Although SLE belugas have been protected from hunting since 1979, little sign of recovery has been observed, and they face many of the same natural and anthropogenic factors as CI beluga whales (DFO[5]).

Review of Natural and Anthropogenic Factors

Natural factors include, but are not limited to, stranding, killer whale, *Orcinus orca*, predation, diseases and parasites, and environmental perturbations such as changes in sea surface temperatures. Anthropogenic factors include pressure on beluga whale prey species from commer-

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ABSTRACT—The endangered population of beluga whales, Delphinapterus leucas, *found year-round in the waters of Cook Inlet, Alaska, is exposed to a variety of natural and anthropogenic processes that, alone or combined, could compromise their conservation and recovery. Natural risks include stranding, killer whale,* Orcinus orca, *predation, diseases and parasites, and environmental change. Anthropogenic factors include pressure on beluga whale prey species from commercial, sport, and subsistence fishing, pollution (other than contaminants), chemical contaminants, vessel traffic, underwater noise, and habitat alteration from development and land use. This review provides a summary of current and potential factors and key gaps in existing knowledge of these factors as they relate to Cook Inlet beluga survival and recovery.*

[1]NMFS. 2008. Conservation Plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). Natl. Mar. Fish. Serv., NOAA, Juneau, Alaska, (avail. at http://www.alaskafisheries.noaa.gov/protectedresources/whales/beluga/mmpa/final/cp2008.pdf), accessed 5 Apr. 2010.

[2]Hobbs, R. C., K. E. W. Shelden, D. J. Vos, K. T. Goetz, and D. J. Rugh. 2006. Status review and extinction assessment of Cook Inlet belugas (*Delphinapterus leucas*). AFSC Proc. Rep. 2006-16, 74 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE., Seattle, WA 98115-6349, (avail. at http://www.afsc.noaa.gov/Publications/ProcRpt/PR%202006-16.pdf), accessed 5 Apr. 2010.

[3]Hobbs, R. C., K. E. W. Shelden, D. J. Rugh, and S.A. Norman. 2008. Status review and extinction assessment of Cook Inlet belugas (*Delphinapterus leucas*). AFSC Proc. Rep. 2008-02, 116 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE, Seattle, WA 98115-6349, (avail. at http://www.nmfs.noaa.gov/pr/pdfs/statusreviews/belugawhale_cookinlet.pdf), accessed 5 Apr. 2010.

[4]Hobbs, R. C., and K. E. W. Shelden. 2008. Supplemental status review and extinction assessment of Cook Inlet belugas (*Delphinapterus leucas*). AFSC Proc. Rep. 2008-08, 76 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE, Seattle, WA 98115-6349 (avail. at http://www.afsc.noaa.gov/Publications/ProcRpt/PR2008-08.pdf), accessed 5 Apr. 2010.

[5]DFO. 2012. Recovery strategy for the beluga whale (*Delphinapterus leucas*) St. Lawrence Estuary population in Canada. Species at Risk Act Recovery Strategy Ser. Fish. Oceans Can., Ottawa, 88 p. (avail. at http://www.sararegistry.gc.ca/virtual_sara/files/plans/rs_st_laur_beluga_0312_e.pdf), accessed 28 Feb. 2014.

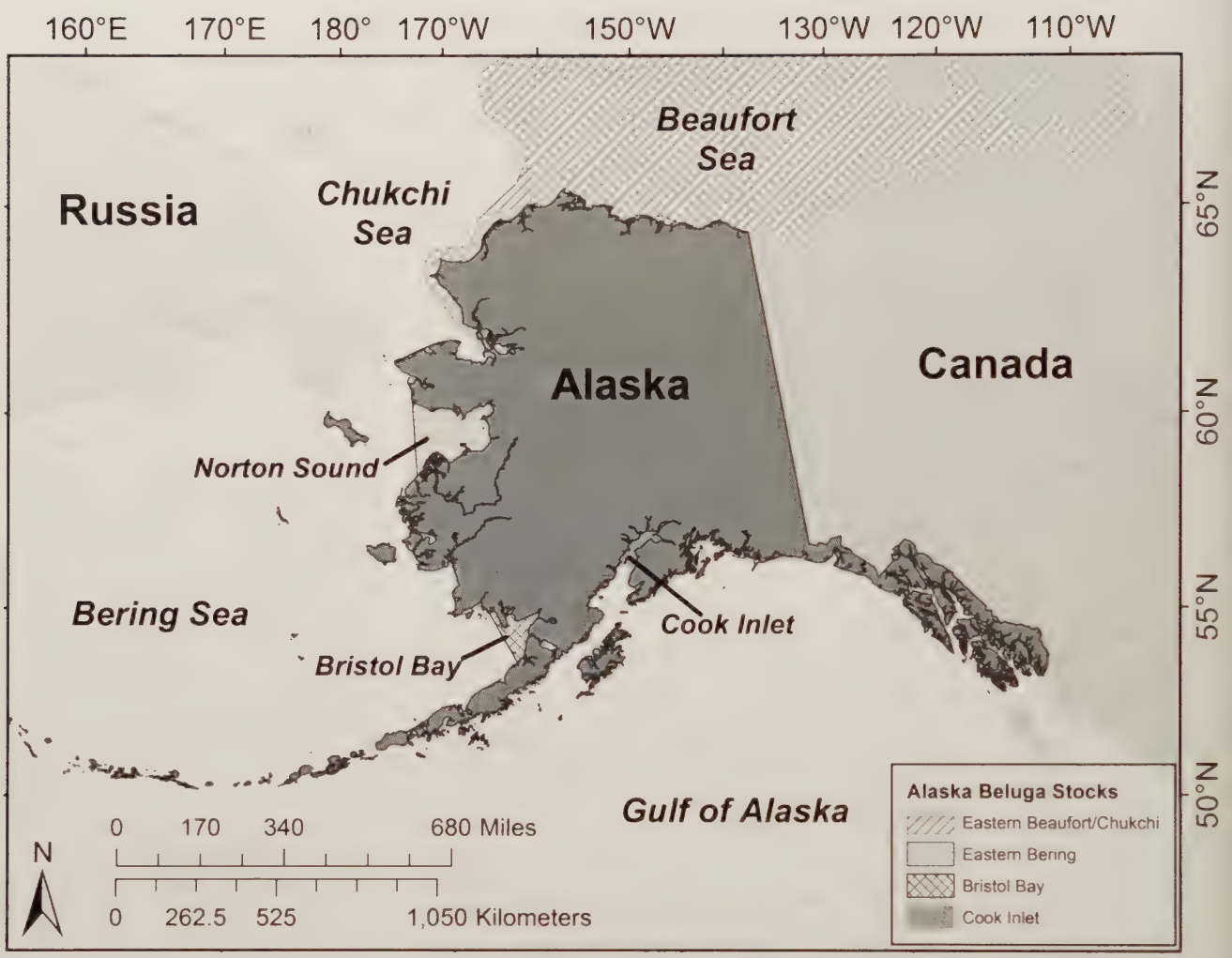

Figure 1.—Summer locations of beluga whale stocks

cial, sport, and subsistence fishing; toxicants (including contaminants), stormwater/surface runoff, vessel traffic, noise, and habitat alteration from land use and development (Norris, 1994). The proximity of CI belugas to nearshore ecosystems places them at particular risk for interactions with human-related activities that may negatively influence their survival (Perrin, 1999).

Though several known and potential effects are described in this review, the degree to which they affect CI beluga whales is unknown. Individual factors are discussed in this review; however, cumulative factors may affect these whales at any time.

Natural Factors

Live-stranding

It is uncertain why beluga whales live strand in Cook Inlet. Belugas in some Canadian populations are known to intentionally ground themselves during molting while rubbing their skin against rocky bottoms (Smith et al., 1992), though CI whales do not appear to go through molt as observed in other higher latitude beluga populations. Beluga whales may also strand purposely or accidentally to avoid predation by killer whales (Shelden et al., 2003), when chasing prey during ebbing tides, or due to injury or illness (Moore et al., 2000). Beluga stranding events in upper Cook Inlet are not unusual (Vos and Shelden, 2005) and may, in part, occur because of extreme tidal heights and long shallow tidal estuaries found in their primary habitat (Goetz et al., 2012), or may be precipitated by anthropogenic-related events such as ship strikes or fishery interactions.

NMFS has compiled reports of approximately 1,076 dead and live stranded whales in Cook Inlet since 1987, when it began actively investigating stranding reports (NMFS[6]). A majority of the strandings involved

[6]NMFS. 2015. Draft recovery plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). Natl. Mar. Fish. Serv., NOAA, Juneau, Alaska,

live whales (n = 874) (NMFS[6]:Table 5, p. 62). Thirty-six live stranding events were reported, with a majority (n = 22; 61%) of these occurring in Turnagain Arm, an area of extensive tidal flats that results in nonlinear flooding and ebbing and strong tidal bore currents with speeds up to 5 m/s (Ezer et al., 2008). These live-stranding events involved both adult and juvenile belugas that were apparently healthy, robust animals. Although many of these events do not appear to directly cause mass mortality, prolonged stranding events that last more than a tidal cycle, such as a result of coastal flooding or tsunamis, may result in an unusual mortality event (UME) (Hobbs et al., 2015b).

Beluga whales are usually able to survive through a stranding event and escape to deeper water on the rising tide. However, some deaths during these events do occur. Once a whale strands, death may result from stress and/or hyperthermia from prolonged exposure. Years with mass strandings (total stranded; mortalities associated with that event) include: 1992 (2; 2), 1996 (60; 4 and 20–30; 1), 1999 (58–70; 5), 2003 (46+; 5), 2005 (7; 1), 2008 (28–30; 2), 2014 (UNK; 2) (NMFS[6]:Table 5, p. 62). The event in 2003 occurred on 28 August, during which at least 46 belugas live-stranded in Turnagain Arm for over 10 h; five whales were suspected to have died as a result of this stranding event (Vos and Shelden, 2005), and one was confirmed by necropsy (Burek-Huntington et al., 2015). In 2014, the NMFS received a report of two stranded beluga whales in Turnagain Arm; however, no live stranding report was received, but necropsy findings suggested they had recently live-stranded which may have contributed to their deaths (Burek-Huntington et al., 2015).

Whales stranding high on a sand bar during an outgoing tide may be exposed for 10 h or more. Unless caught in an overflow channel or ponded area and partially covered with water, the whale may have difficulty regulating body heat. An extensive network of capillaries within the flukes and flippers allows belugas to lose excess body heat to the environment, and these structures must be submerged for this mechanism to function properly and regulate body temperature, preventing overheating (Geraci and Lounsbury, 2005). Additional stress is placed on internal organs and breathing may be difficult without the support provided by water. Overall, live-stranding may contribute to reduced fitness in CI whales.

Delayed physiological consequences from stranding may include rhabdomyolysis and cardiomyopathy, resulting in kidney damage and decreased immune function (Turnbull and Cowan, 1998; Herráez et al., 2007; Moore et al., 2013). Of 38 stranded belugas, the majority (n = 25; 66%) were adults, with 8 of 11 mature females either pregnant, post-partum, or lactating, and 9 thought to have restranded dead following a prior live stranding. Four of the adults were single strandings with no significant findings detected. It is hypothesized that large, particularly pregnant, belugas may be more susceptible to mortality following a live stranding event (Burek-Huntington et al., 2015) due to the increased cardiovascular stresses.

Predation

Cook Inlet beluga whales are preyed upon by killer whales, their only known natural predator. Mortality occurs through direct predation, or indirectly by increasing live stranding events as belugas flee into shallow water to escape. Killer whales are more commonly found in lower Cook Inlet and the Gulf of Alaska (Shelden et al., 2003; Matkin et al., 2012; Matkin et al.[7]) where they may feed on a variety of prey, while the number visiting the upper inlet appears to be small. They occur infrequently, with no more than six individuals in each sighting reported to NMFS since 1982 (Shelden et al., 2003; Matkin et al.[7]).

Killer whale ecotypes include resident, transient, and offshore. Transients feed exclusively on marine mammals and have dorsal fins distinct in shape from resident and offshore orcas. Photographs of the dorsal fins of killer whales that stranded in Turnagain Arm revealed that they were transients (Shelden et al., 2003); however, resident types (fish eaters) also occur in the inlet. Therefore, a sighting of killer whales in proximity to belugas does not necessarily mean they are feeding on them.

No confirmed killer whale sightings were noted in the upper inlet from 2004 to 2012 by researchers who spent many hours on the water during the CI beluga photo-identification project (McGuire et al.[8]). Since 1982, NMFS has received reports of killer whales in the vicinity of Turnagain Arm, Knik Arm, between Fire Island and Tyonek, near the Chuitna River, near rivers along the Susitna Delta, and near the Kenai River (Shelden et al., 2003).

Native hunters report that killer whales are usually found along the tide rip that extends from Fire Island to Tyonek (Huntington, 2000). Recent directed studies of killer whales during 2008–09 did not observe any beluga predation; however, weather, tidal conditions, and scarcity of encounters precluded adequate detection of the former (Matkin et al.[7]).

Although only opportunistic data exist on the removal of beluga whales in Cook Inlet due to killer whale predation, a detailed review of stranding and suspected killer whale predation reports from this region (1982–2013), appears to suggest a minimum esti-

(avail. at http://www.nmfs.noaa.gov/pr/recovery/plans.htm#mammals), accessed 30 Jul. 2015.

[7]Matkin, C. O., L. B. Lennard, R. Andrews, and J. Durban. 2011. Predation by killer whales in Cook Inlet and western Alaska: an integrated approach 2008-2009. Proj. R0303-01 Final Rep. – Rev. April 2011 (avail. at http://alaskafisheries.noaa.gov/protectedresources/whales/killerwhales/reports/predation_ci_042011.pdf), accessed 22 Apr. 2012.

[8]McGuire, T., A. Stephens, and L. Bisson. 2014. Photo-identification of Cook Inlet beluga whales in the waters of the Kenai Peninsula Borough, Alaska. Final Rep. Field Activities Belugas Identified 2011–2013. Rep. prep. by LGL Alaska Res. Assoc., Inc., Anchorage, for the Kenai Peninsula Borough, 92 p, (avail. at http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/reports/2011_2013photoid0114.pdf), accessed 10 Apr. 2014.

mate of approximately one predation event per year, which does not include three CI belugas suspected to have died as a direct result of killer whale predation in which calves accompanied adults that were attacked (Shelden et al., 2003). Injuries on additional belugas were deemed possible killer whale interactions (Burek-Huntington et al., 2015; Hobbs and Shelden[4]). On 23 Sept. 2000, an NMFS enforcement agent observed 3–5 killer whales chasing beluga whales in Turnagain Arm (Shelden et al., 2003). Within the next few days, two lactating female beluga whales were found dead with teeth marks, internal hemorrhaging, and other injuries consistent with killer whale attacks. Though the impact of killer whale predation on the CI beluga population remains unknown, if killer whale predation occurs at a rate equivalent to or greater than beluga reproduction, it could prevent recovery or reduce the beluga population, as demonstrated in population viability analysis modeling (Hobbs et al., 2015b).

Infectious Diseases

Infectious diseases include diseases caused by pathogenic bacteria, viruses, and parasites. Epidemiological theory suggests that species are driven to extinction by pathogens only under specific conditions: 1) the pre-epidemic host population size is small (i.e., the species is endangered), 2) the pathogen/parasite relies on non-density dependent transmission between hosts, or 3) when the pathogen reservoir is the abiotic environment (de Castro and Bolker, 2005). While infectious disease may not cause the complete extinction of the species, it can produce enough mortality to threaten the species or trigger the disappearance of local stocks or populations, increasing the risk posed by other mechanisms (de Castro and Bolker, 2005). Small population size is the most widely cited driver of disease-induced extinction of the three previously mentioned conditions. Lack of genetic variability is another feature of the risk associated with small population size. The lack of genetic variability in a species, or stock, may reduce the range of immune responses in the population, leaving it more susceptible to disease (O'Brien and Evermann, 1988).

This suggests that disease alone is unlikely to drive a species to extinction, but may be much more likely to do so when a highly virulent and transmissible pathogen is introduced into the population in combination with other contributing risk factors such as high toxin exposures, habitat loss, and human disturbance (Smith et al., 2006; Anthony et al., 2012). Relatively few published reports are available on infectious disease exposure and occurrence in wild belugas with most reports coming from studies of SLE belugas (Wazura et al., 1986; Martineau et al., 1988; Barr et al., 1989; De Guise et al., 1995a; Mikaelian et al., 2000; Nielsen et al., 2001; Martineau et al., 2003; Maggi et al., 2008; Lair et al.[9]).

In SLE beluga whales, infectious disease was the most common cause of death with 32% attributed to a variety of bacterial, parasitic, and viral infections (Lair et al.[9]). In Cook Inlet, characterization of infectious disease threats has been complicated by small sample sizes, lack of access to live animals, and the poor quality of most of the carcasses examined up to this point (Burek-Huntington et al., 2015).

An analysis of necropsy results from 38 beluga whales that stranded from 1998 to 2013 revealed that in 11 (29%) cases, a definitive cause of death was not determined due to moderate to advanced decomposition (Burek-Huntington et al., 2015). Infectious disease is one of the factors that is difficult to histologically evaluate in carcasses in poor condition due to the loss of ability to detect pathogens and their effects on tissues. However, three (8%) CI beluga deaths were attributed to infectious disease; one was due to systemic herpesvirus causing widespread vasculitis, and two had multiple mixed bacterial and parasitic diseases (Burek-Huntington et al., 2015).

Parasites are commonly found in wild mammals, but their role in causing morbidity and mortality depends on load and pathology produced in the particular host. The extent of tissue involvement and associated host response led to the designation of parasitic infections as contributory and/or incidental disease findings in stranded CI beluga whales (Burek-Huntington et al., 2015). Mild (i.e., incidental) lungworm infections were reported in 14 of the 38 (37%) necropsied whales and were identified as *Stenurus arctomarinus* (Burek-Huntington et al., 2015).

In hunter-killed belugas from the Churchill River basin in Manitoba, Canada, 89% (8 of 9) were parasitized with the lungworm *Pharurus pallasii* in the lung, accessory sinuses, ear canal, and cerebral spinal fluid (Kenyon and Kenyon, 1977). In another study on SLE whales, lungworm prevalence in adults and juveniles was 88 and 72%, respectively (Houde et al., 2003), and included *Pharurus pallasii* as well as *Stenurus arctomarinus* (Measures et al., 1995, 2001).

The hunter-killed whales were assumed to represent normal healthy animals with parasite loads representative of endemic levels. The lungworms in the SLE whales were thought to commonly contribute to mortality. Since pneumonia is a common finding in stranded cetaceans, it is unclear whether lungworms alone, or in combination with secondary bacterial infections, are the causative factor in mortality due to pneumonia in these strandings (Leeney et al., 2008).

The nematode, *Crassicauda giliakiana*, was detected in the majority (74%) of CI beluga cases in which the kidneys were examined (Burek-Huntington et al., 2015). In these infections, there was tissue damage and formation of large mineralized granulomas in the kidneys, at times extensive. It is unclear whether this results in functional damage to the kidneys (Burek-Huntington et al., 2015); how-

[9]Lair, S., D. Martineau, and L. N. Measures. 2014. Causes of mortality in St. Lawrence Estuary beluga (*Delphinapterus leuca*) from 1983 to 2012. DFO Can. Sci. Advis. Sec. Doc. 2013/119. Iv + 37 p.

ever, it is possible that with very heavy infestation, there could be replacement of enough of the kidney (66–75% of the kidney tissue) to affect function or obstruction of urine outflow.

Another related parasite, *C. boopsis* is thought to limit population growth in fin whales, *Balaenoptera physalus* (Lambertsen, 1986, 1992). This parasite also causes granulomas in the kidney similar to *C. giliakiana*; however, it also causes extensive thromboembolism and inflammation in the blood vessels (phlebitis) systemically. Severe secondary effects of thromboembolism to other organs with *C. giliakiana* have not been observed to date in CI whales, so it is most likely that under usual circumstances and levels of infestation, these animals live with this parasite with no clinical effects (Burek-Huntington et al., 2015).

Parasites of the stomach (*Anisakis* sp.) were often present in CI beluga whales with little significant pathology. These infestations were not considered extensive enough to cause clinical signs, although *Anisakis* sp. nematodes were associated with perforating stomach ulcers in Canadian belugas and attributed as cause of death in 4% of cases (Lair et al.[9]).

Other incidental parasitic infections in CI belugas included protozoa encysted in the skeletal muscle, morphologically consistent with *Sarcocystis* sp. and nematodes surrounded by parasitic granulomas at the blubber–muscle junction (Burek-Huntington et al., 2015). All have been previously reported in other populations (De Guise et al., 1993; Lair et al.[9]). CI beluga whales were free of ectoparasites, although both the whale louse, *Cyamus* sp., and acorn barnacles, *Coronula reginae*, have been observed on beluga whales located outside of Alaska (Klinkhart[10]).

While a variety of infectious diseases occur in CI belugas, relatively little indication exists that their occurrence has had any measurable negative impact on the health of this population with such few cases available for analysis. It is possible that the difference in rates of mortality due to infectious disease between CI and SLE belugas is due to the immunosuppressive effects of much higher contaminant loads in SLE whales (Martineau et al., 2003; Burek-Huntington et al., 2015). Even if currently not thought to be a significant factor, the increased incidence of existing diseases or emergence of previously unknown diseases could cause a significant impact on the survival and fecundity of this small population, ultimately impacting its status and recovery.

Epidemiology of infectious disease is expected to change due to climate change (Beugnet and Chalvet-Monfray, 2013), for a variety of reasons including changes in host density due to reduced habitat, increased survival of pathogens in the environment, range extensions of host species and vectors, and changes in body condition due to changes in predator-prey relationships (Burek et al., 2008). More beluga whales strand than are reported and/or necropsied. Given the challenges of responding to reported strandings and the often delayed response due to remoteness or inaccessibility, the data gathered from the few that have been necropsied, though inconclusive, provide extremely important clues in determining the potential consequences of disease, parasitism, poor nutrition, and environmental stressors on this vulnerable population.

Noninfectious Diseases

Noninfectious diseases, such as neoplasia and exposure to biotoxins, have not been found in examinations of CI beluga whales. Small numbers of animals have been tested for the presence of harmful algal bloom toxins, domoic acid, and microcystins, and all have been either negative or at clinically insignificant levels (Burek-Huntington et al., 2015). Neoplasia, which was listed as a common finding in SLE beluga causes of death, was not detected in the 38 cases examined in Cook Inlet. Neoplasia seen in SLE whales included adenocarcinomas of the salivary gland, uterus, and gastrointestinal tracts (Girard et al., 1991; Lair et al., 1998; Martineau et al., 2003; Lair et al.[9]). The hypothesis for this high rate of occurrence in SLE belugas was the extremely high levels of contaminants (De Guise et al., 1994, 1995b; Martineau et al., 1988, 1999, 2002; Lair et al.[9]).

Climate Change

The Cook Inlet ecosystem is very dynamic and experiences continual change in its physical composition, with strong currents, extreme tidal changes, and large silt volumes deposited from glacial scouring. Climatic changes in this region are driven by the Alaska Coastal Current (Di Lorenzo et al., 2008; Weingartner[11]). The environment in which belugas reside make them susceptible to entrapment in ice and more vulnerable to entrapment during sudden ice formations, freeze-ups, and when winds change, driving ice into once open areas (Armstrong, 1985; Heide-Jørgensen et al., 2002). Though entrapments appear to rarely result in mass mortalities, under-reporting is possible given these incidents occur during the winter months. In general, CI beluga whales appear to prefer ice-covered waters during the winter period, and the likelihood of entrapment is low as no entrapments have been reported (Shelden et al., 2015). However, as weather patterns become more unpredictable and extreme as a result of climate change, CI belugas may face greater risk of ice entrapment with increased frequency and scale of mortality.

Temperature and salinity gradients exist between lower and central Cook Inlet, between the east and west sides of the inlet (Okkonen and Howell, 2003; Okkonen et al., 2009). A study investigating stream temperatures in the Cook Inlet basin and their impli-

[10]Klinkhart, E. G. 1966. The beluga whale in Alaska. State of Alaska Dep. Fish. Game, Juneau, Fed. Aid Wildl. Restor. Proj. Rep. Vol. VII, Proj. W-6-R and W-14-R, 11 p.

[11]Weingartner, T. 2007. Long-term oceanographic monitoring of the Gulf of Alaska ecosystem. Exxon Valdez Oil Spill Trustee Counc. Annu. Proj. Rep., Proj. 070340, 2 p. (avail. at http://www.evostc.state.ak.us/Store/AnnualReports/2008-070340-Annual.pdf), accessed 1 May 2012.

cations of climate change, observed that water temperatures are a valuable measure and descriptor of biological, chemical, and physical characteristics of rivers and streams in the Cook Inlet basin (Kyle and Brabets, 2001). This is considered significant as fish health and populations are greatly affected by water temperature conditions.

Fifteen sampling sites in Cook Inlet have a predicted water-temperature change of 3°C or more over the next 100 years, which is considered significant for the incidence of disease in fish populations (Chatters et al., 1991). Negative changes to the health or habitat of beluga prey species, such as those due to abnormal or extreme water temperatures, may reduce prey availability or distribution, resulting in potentially negative impacts on the health and reproduction of the beluga population due to decreased energy intake or increased energy expenditure seeking out prey.

Freshwater flow into Cook Inlet from melting snow pack may be altered during climate change, affecting salinity, composition, and levels of water nutrients (Royer et al., 2001). Beluga prey density and distribution in the upper inlet may also be influenced by alterations in flow. Seasonal changes in the freshwater inputs drive seasonal changes in the salinity of the Cook Inlet region. Salinity levels are important for salmonids as they progress toward the sea from the presmolt to smolt stage (Otto and McInerney, 1970) and particularly for the maintenance of planktonic communities the young fish consume (Eslinger et al., 2001; Speckman et al., 2005). Loss of sea ice and increased ocean temperatures will likely effect changes in prey distribution, composition, and productivity, which will in turn present foraging challenges for beluga if their preferred prey is not found in their usual habitats, requiring greater energy expenditure for foraging effort or resorting to lower quality prey.

Rather than directly coming from the effects of changing weather conditions, more serious influences of climate change on CI belugas may result indirectly from the role that regional warming and decreased sea ice play in modifying human activities. In light of decreasing ice coverage, ships may reach areas in the winter that were previously inaccessible due to extensive sea ice. Reductions in sea ice that allowed an increase in ship traffic, could result in ships strikes becoming an increasingly significant cause of injury and death, as well as an increased disturbance by ship noise.

Anthropogenic Factors

The major urban center of Alaska is located within the Cook Inlet region, with over 435,000 people, or approximately 2/3 of the state's population, residing in the Anchorage, Matanuska-Susitna, and Kenai Peninsula Boroughs (U.S. Census Bureau[12]). This number of people in a relatively small area presents added concerns for CI beluga whales and their natural environment. The following anthropogenic factors were evaluated, as they are considered to be the human-related factors of most concern for the beluga and other cetacean species: pressure on fish stocks from commercial, sport, and subsistence fishing; pollution (nonpoint and point-source); vessel traffic; noise; and land use and development (NMFS[1]).

Pressure on Prey Fish from Commercial, Sport, and Subsistence Fishing

Beluga whales are viewed as top predators in the food chain and, from a global perspective, their diets vary regionally and seasonally (Stewart and Stewart, 1989). CI belugas appear to feed on a wide variety of prey, focusing on specific species when they are seasonally abundant. In summer, Pacific salmon are preferred, particularly chum, *Oncorhynchus keta;* coho, *O. kisutch;* and Chinook, *O. tshawytscha*. During autumn, as anadromous fish runs near their end, fish species found in nearshore bays and estuaries again return to the beluga diet. This includes species observed in the spring diet, such as eulachon, *Thaleichthys pacificus*, and sculpin, Cottidae; cod, Gadidae; and flatfish, Pleuronectidae (Quakenbush et al., 2015).

Fisheries may compete with beluga whales for salmon and other prey. The mean number of all salmon species caught annually in commercial fisheries in upper Cook Inlet from 1956 to 2012 was 4,191,748 salmon (ADFG[13]), with fluctuations ranging from 1,064,485 (1959) to 10,564,618 (1992) (Shields[14]) (Fig. 2). In lower Cook Inlet, catches ranged from a low of 103,936 in 1974 to 3,737,393 salmon in 1982 (Fig. 2) (Bucher and Morrison[15]; Hammarstrom and Ford[16]). It is unknown how fluctuations in salmon run strength affect belugas or how fishing pressure is impacting their prey stocks. It is also unknown what proportion of the fish targeted by the upper and lower inlet fisheries constitute key prey items or populations in the diet of the beluga whale.

There is a strong indication that these whales are dependent on access to relatively dense concentrations of high nutritional value prey. Any reduction in the ability of beluga whales to access or utilize spring and summer foraging habitat, or of preferred prey availability, may reduce beluga energetics and delay their recovery (Williams et al., 2006; Ford et al., 2010).

[12]U.S. Census Bureau. 2011. Basic counts/population – Alaska. Am. Factfinder (avail. at http://www.census.gov/), accessed 22 Apr. 2012.

[13]ADFG. 2014. Alaska Dep. Fish Game, Div. Commer. Fish., Central Reg., (avail. at http://www.adfg.alaska.gov/index.cfm?adfg=fishingCommercialByArea.southcentral), accessed 1 Mar. 2014.

[14]Shields, P. 2010. Upper Cook Inlet commercial fisheries annual management report, 2009. Alaska Dep. Fish Game, Fish. Manage. Rep. No. 10-27, Anchorage, 172 p. (avail. at http://www.adfg.alaska.gov/FedAidpdfs/FMR10-54.pdf), accessed 22 Apr. 2012.

[15]Bucher, W. A., and R. Morrison. 1990. Review of the 1990 lower Cook Inlet salmon fishery. Rep. to Alaska Board Fish., Reg. Info. Rep. 2H90-10, 30 p. Alaska Dep. Fish Game, Div. Commer. Fish., Central Reg., Anchorage (avail. at http://www.sf.adfg.state.ak.us/FedAidPDFs/RIR.2H.1990.10.pdf), accessed 13 Aug. 2010.

[16]Hammarstrom, L. F., and E. G. Ford. 2010. 2009 Lower Cook Inlet Annual Finfish Management Report. Alaska Dep. Fish Game, Fish. Manage. Rep. 10-17, 144 p. (avail. at http://www.adfg.alaska.gov/FedAidPDFs/FMR10-17.pdf), accessed 13 Aug. 2010.

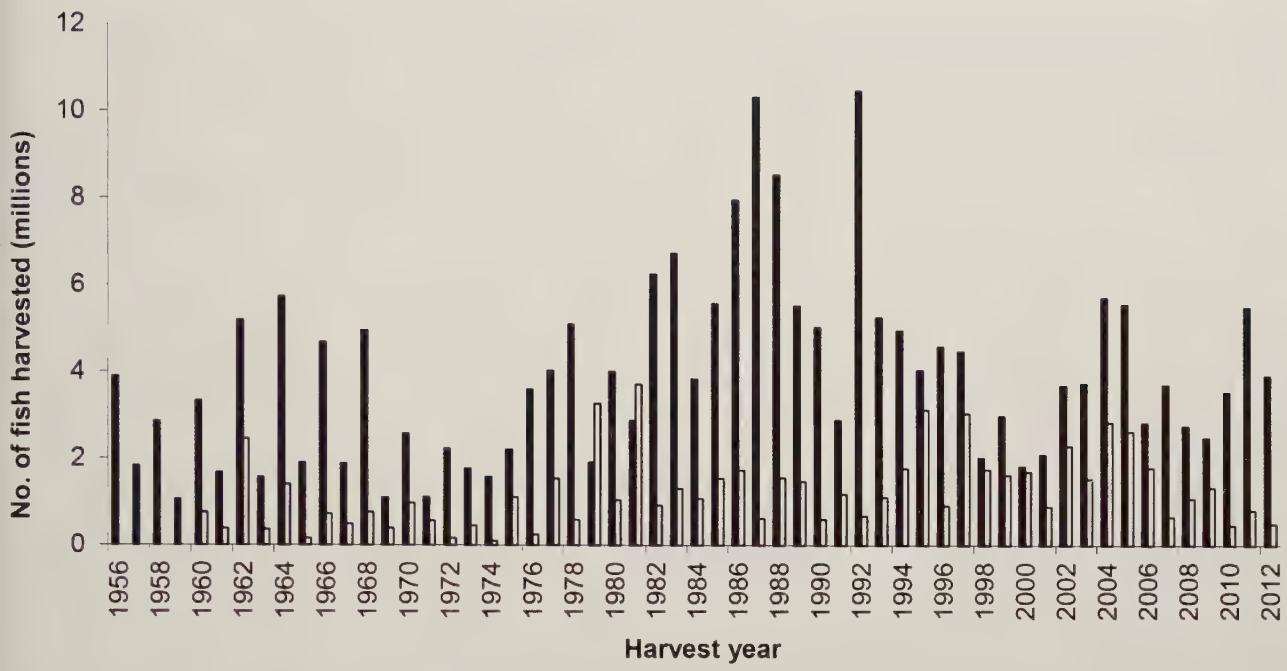

Figure 2.—Commercial salmon (coho, chum, Chinook, pink, sockeye) harvest (all gear and harvest types) for upper (black bars) and lower (white bars) Cook Inlet, 1956-2012 (Bucher and Morrison (text footnote 15); Hammarstrom and Ford (text footnote 16); Shields (text footnote 14); ADFG (text footnote 13)).

Contaminants

Exposure to contaminants and toxicants, such as persistent organic pollutants (POPs), polyaromatic hydrocarbons (PAHs), and heavy metals associated with human activities, is a concern for beluga whale health and subsistence use (Becker et al., 2000). The principal sources of anthropogenic toxicants in the marine environment are 1) discharges from municipal wastewater treatment systems; 2) accidental spills or discharges of petroleum, ship ballast, and other hazardous substances; and 3) runoff from urban, mining, and agricultural areas (Moore et al., 2000).

Persistent Organic Pollutants (POPs)

Persistent Organic Pollutants (POPs) include many compounds and are defined as organic contaminants that persist in the environment due to their resistance to degradation, and bioaccumulation in the food chain with the best known examples being the polychlorinated biphenyl (PCBs), dieldrins, chlorinated herbicides such as DDT, in addition to others. Detrimental effects of POPs in marine mammals include, but are not limited to, reproductive disorders (Helle et al., 1976; Béland et al., 1993; Martineau et al., 1994), immune system depression (De Guise et al., 1995b; de Swart, 1996; Ross, 1995), and subsequent greater risk of infection (Jepson et al., 1999, 2005; Hall et al., 2006).

However, the effects on the health of the animal are often difficult to discern. For instance, no experimental studies on the reproductive effects of contaminants in cetaceans have been performed, and direct evidence for the association is lacking (O'Hara and O'Shea, 2001). Nevertheless, organochlorines (OCs) are suspected to be broadly affecting the health and reproduction of cetaceans globally through disruption of endocrine receptors (Colborn and Smolen, 1996; Martineau et al., 2003).

Some contaminants and toxins have been detected in different matrices such as water column, benthic sediment, and river samples in Cook Inlet (Savoie et al.[17]). Although no cause-and-effect relationship has been established between contaminants (e.g., PCB and perfluorooctane sulfonate [PFOS]) and reproductive disorders in belugas, researchers have suspected that elevated organochlorines are associated with reproductive failure (Béland et al., 1993; Martineau et al., 1994; URS Corp.[18]). Small numbers of several classes of POPs tested in

[17]Savoie, M. A., G. Gillingham, and S. M. Saupe. 2012. Integrated Cook Inlet environmental monitoring and assessment program (ICIEMAP). Poster presented at 2012 Alaska Marine Science Symposium, Anchorage, Alaska, 16-20 January 2012 (avail. at http://www.alaskamarinescience.org/), accessed 28 Feb. 2014.

[18]URS Corporation. 2010. Chemical exposures for Cook Inlet beluga whales: a literature review and evaluation. Rep. for Natl. Mar. Fish. Serv., Reg. Office, Anchorage, Alaska, NMFS Contr. AB133F-06-BU-0058 (avail. at http://www.fakr.noaa.gov/protectedresources/whales/beluga/reports/cibtoxicology0310.pdf), accessed 16 Mar. 2011.

hunter-killed samples have been tested in CI beluga whales and have been found to be lower than any other North American beluga stocks, with the SLE whales at highest levels (Becker et al., 2000).

Hydrocarbons There is a diverse array of natural and anthropogenic sources of hydrocarbons to Cook Inlet (Driskell and Payne[19]) that could pose a concern for beluga health and reproduction. Large oil spills present one of the greatest short-term threats to coastal life, whereas point-source discharges and nonpoint sources of petroleum contamination pose chronic risks.

In addition, spills of hazardous substances such as urea, sulfur dioxide, and ammonia are also of concern and may occur on land and at sea (ADEC[20]). Elevated levels of the POPs BTEX (benzene, toluene, ethylbenzene, and xylenes) were detected in the water column at three locations in upper Cook Inlet (two near Trading Bay and one near East Foreland) warranting further investigation (Savoie et al. [17]). Coastal cetaceans may contact petroleum during migration, feeding, or breeding. Inhalation of vapors at the water's surface and ingestion of hydrocarbons during feeding are more likely pathways of exposure. Acute exposure to petroleum products can cause reduced activity and behavioral changes, lung congestion, pneumonia, inflammation of the mucous membranes, liver disorders, and neurological damage (Geraci and St. Aubin, 1990).

A recent study documented adverse health consequences in a population of bottlenose dolphins, *Tursiops truncatus*, in Louisiana subsequent to the Deepwater Horizon oil spill (Schwacke et al., 2013). Oil and petroleum product production, refining, and shipping in the inlet present a possibility for oil and other hazardous substances to be spilled, negatively impacting marine species in the inlet. As such, both the immediate and the cumulative effects of such an event are considered potentially adverse.

The Outer Continental Shelf Environmental Assessment Program estimated that 3,339 m^3 (21,000 barrels) of oil were spilled in the inlet between 1965 and 1975, while 1,590 m^3 (10,000 barrels) were spilled from 1976 to 1979 (MMS[21]). Major spills of oil and other harmful substances have occurred over the past two decades (Table 1; ADEC[20]). Oil spills may also be destructive to beluga prey, and may, therefore, adversely affect the whales by reducing food availability and serving as a source of exposure through ingestion. Clinical exposure trials, used to evaluate the effect of PAHs, such as those found in crude oil, demonstrated adverse cardiac function in fish embryos (Incardona et al., 2010).

PAHs are also carcinogenic (Martineau et al., 2003). St. Lawrence belugas have a higher rate of malignant neoplasia than reported for any other cetacean population, with 18% of deaths attributed to this disease in a study of 129 examined carcasses (Martineau et al., 2003). One hypothesis is that the high levels of PAHs in substrates, along with bottom feeding of belugas on benthic invertebrates may, partially or fully, explain the exposure responsible for these neoplasms (De Guise et al., 1994, 1995b; Martineau et al., 1988, 1994, 2003; Lair et al.[9]).

With the low levels of neoplasia in CI beluga whales, it would be reasonable to hypothesize that tissue levels of these contaminants are relatively low; however, these compounds have not been tested, so the tissue levels in CI belugas are unknown, which is a significant data gap. Studies on PAHs in archived CI beluga liver and blubber tissue demonstrated the presence of PAH levels at the highest concentrations in adult females and fetuses, warranting further study of the bearing of these chemicals on reproductive success and subsequent population recovery (see Saupe et al.[22]).

Essential and nonessential heavy metals Trace elements and heavy metals have been investigated in several populations of beluga whales, including those in Cook Inlet (Becker et al., 2000). Copper concentrations in the liver were 2–3 times higher in CI whales compared to those in the Beaufort and eastern Chukchi Seas, but were more similar to levels recorded in Hudson Bay, Can., belugas (Becker et al., 2000). CI beluga liver copper levels were consistently higher (mean = 160 mg/kg) than levels at which kidney damage (mean = 29 mg/kg) was reported in bottlenose dolphins in Australia (Lavery et al., 2009; URS Corp.[18]).

However, further evaluation of hepatic copper levels is needed to provide insight into the potential for kidney damage in CI beluga whales because the toxicological implication of elevated copper levels in this species is unknown. Being an essential element, it is regulated metabolically in vertebrates and varies among and within species (Thornburg, 2000). Copper does not appear to accumulate with age, with the highest copper concentrations usually found in younger animals (Becker et al., 2000). Diversity in prey consumed may influence the differing concentrations of this element between CI and other Alaska beluga populations.

Attempts at linking disease epizootics, neoplasia, and other health effects with elevated contaminant levels in marine mammals have prov-

[19]Driskell, W., and J. Payne. 2012. Integrated Cook Inlet monitoring and assessment program (ICIEMAP): hydrocarbon fingerprinting. Poster presented at 2012 Alaska Marine Science Symposium, Anchorage, Alaska, 16-20 January 2012 (avail. at http://www.alaskamarinescience.org/), accessed 28 Feb. 2014.

[20]ADEC. 2011. Major oil spills to coastal waters. Spill prevention and response. Alaska Dep. Environ. Conserv., Div. Water (avail. at http://www.dec.state.ak.us/water/wqsar/index.htm), accessed 1 Mar. 2014.

[21]MMS. 1996. Cook Inlet planning area oil and gas lease sale 149. Final Environ. Impact Statement. U.S. Dep. Interior, Minerals Manage. Serv., Alaska OCS Reg.. (avail. at http://www.boem.gov/ak-eis-ea/), accessed 22 Oct. 2010.

[22]Saupe, S. M., T. M. Willette, D. L. Wetzel, and J. E. Reynolds. 2014. Assessment of the prey availability and oil-related contaminants in winter habitat of Cook Inlet beluga whales. Final report of field surveys and laboratory analyses (2011-2013). Rep. prep. by Cook Inlet Reg. Citizens Advisory Counc. (RCAC) for Kenai Peninsula Borough, 53 p.

Table 1.—Select spills of petroleum products in Cook Inlet (ADEC text footnote 20).

Date	Vessel	Location	Product	Amount	Notes
2 July 1987	Tanker/Vessel (T/V) *Glacier Bay*	Near Nikiski	Crude oil	214.6-604.2 m^3 (1,350-3,800 barrels)	Belugas noted in area of spill; but unknown if any adverse impacts inflicted.
21 Aug. 1989	T/V *Lorna B*	0.5 mile N of Steelhead Oil Platform, Upper Cook Inlet	Diesel	404 m^3 (2,540 barrels)	Became entangled in tow cable while towing barge supporting the platform reconstruction.
3 Jan. 1992	Oil pipeline rupture	Port Nikiski	Crude oil	36 m^3 (302 barrels)	
5 Dec. 1995	Tank overfill	Tesoro Refinery, Kenai	Crude oil	22 m^3 (181 barrels)	
6 Mar. 1997	Steelhead Offshore Platform	Upper Cook Inlet	Diesel	35 m^3 (286 barrels)	
15 Jan. 2009	M/V *Monarch*	Granite Point Platform, central Cook Inlet	Diesel; lube oil; unspecified chemicals	172 m^3 (1,080 barrels) – diesel; 3.5 m^3 (22 barrels) lube oil	An estimated 700 barrels of diesel fuels and lube oils unaccounted for.
9 Jan. 2012	XTO Onshore Facility	Nikiski	Crude oil; processed water	32 m^3 (200 barrels) mixed crude and process water	Due to faulty gasket on an access plate located on one of their tanks.

en challenging, given the relatively small number of studies; however, indirect evidence of negative effects has been documented (O'Hara and O'Shea, 2001). In the United Kingdom and Canada, several studies have investigated the potential impact of contaminants on marine mammal immunity and health status (Martineau et al., 1994, 1999, 2002; Jepson et al., 1999, 2005; Hall et al., 2006; Pierce et al., 2008), while more direct studies of contaminants and immunosuppression have been performed in harbor seals, *Phoca vitulina* (de Swart et al., 1996; Ross et al., 1996). Levels of contaminants in blubber of beluga whales can be compared to the threshold levels established for other species of marine mammals to determine the level of risk posed by exposure to these compounds. However, caution is warranted in these evaluations, as the threshold effects levels were determined for non-beluga species, and beluga whales may be more or less susceptible to the toxicological effects of these compounds.

Municipal waste and terrestrial-source pathogens In principal, sources of toxicants in the marine environment may be oil spills, runoff from urban development, vehicle and airplane drippings, human and veterinary pharmaceuticals, and byproducts of activities that do not enter wastewater treatment systems, such as agriculture and mining (Moore et al., 2000). Water quality is a concern for wildlife, with cetaceans vulnerable to infections attributable to terrestrial-source fecal pathogens, antibiotic resistant strains of terrestrial-source bacteria, and wastewater treatment system discharges. Monitoring for indicator organisms (e.g., fecal indicator bacteria) and pathogens within Cook Inlet may provide better insight into the extent to which belugas could be exposed. The ecology of fecal bacteria and protozoal organisms entering nearshore aquatic environments within the inlet is not well understood, though it is recognized that fecal by-products from humans and terrestrial animals may affect the quality of water and food resources in coastal ecosystems (Lisle et al., 2004; Miller et al., 2006).

Ten communities currently discharge treated municipal wastes into the inlet, five of which conduct only primary treatment (EPA[23]). Wastewaters from the Municipality of Anchorage, Nanwalek, Port Graham, Seldovia, and Tyonek receive only primary treatment, while wastewaters from Homer, Kenai, and Palmer receive secondary treatment (NOAA[24]). Eagle River and Girdwood have modern tertiary treatment plants (Moore et al., 2000). Wastewater entering these plants may contain a variety of organic and inorganic pollutants, and may be further dispersed in mixing zones which are areas of water downstream from or surrounding a treatment facility discharge point where the effluent plume being diluted by the water may exceed water quality standards specified by the Clean Water Act and state specifications (ADEC[25]).

Coastal human development contributes to the presence of protozoal and bacterial organisms, emergence of harmful algal blooms, and presence of antibiotic resistant organisms in aquatic ecosystems (Johnson et al., 1998; Scholin et al., 2000; Miller et al., 2002; Blackburn, 2003; Wong et al.[26]), potentially exposing CI belugas due to their preference for nearshore marine ecosystems.

[23]EPA. 2004. Primer for municipal waste water treatment systems. Environ. Protect. Agency, Doc. EPA 832-R-04-001 30 p. (avail. at http://www.epa.gov/own/primer.pdf), accessed 9 Feb. 2012.

[24]NOAA. 2003. Subsistence harvest management of Cook Inlet beluga whales. Final Environmental Impact Statement. Alaska Reg., Nat. Mar. Fish. Serv., NOAA, 180 p. (available from https://alaskafisheries.noaa.gov/protectedresources/whales/beluga/eis2003/final.pdf), accessed 9 Feb. 2012.

[25]ADEC. 2010. Water quality standards, assessment and restoration. Alaska Dep. Environ. Conserv., Div. Water (avail. at http://www.dec.state.ak.us/water/wqsar/index.htm), accessed 9 Feb. 2012.

[26]Wong, S. K., E. Jensen, and W. Van Bonn. 2002. Ciprofloxacin resistance associated with marine mammals. Proceedings of the 42nd Interscience Conference on Antimicrobial Agents and Chemotherapy, 27-30 September 2002, San Diego, CA. American Society for Microbiology, Washington, D.C., p. 86.

A number of fecal bacteria and parasites can be transmitted through waterborne routes and are potential pathogens to both humans and animals, whereas viruses tend to be more host-specific and less likely to cross species. Fecal coliform and *Enterococcus* spp. counts are monitored by ADEC, but a rigorous survey of the microbiological quality of the water and sediment in and around Anchorage has not been attempted (ADEC[25]). Water and sediment samples collected from effluent and multiple coastal waterways in and around Anchorage were found to contain terrestrial-source fecal indicators and pathogens. In this same study, microbial source determination provided evidence of human-source pathogen pollution that could adversely affect beluga health (Norman et al., 2013).

Many current or planned mining projects are ongoing in the Cook Inlet Basin (ADNR[27]). Mined resources include coal, precious metals, and lead. The coastal zones may be developed and utilized during mining operations. Mine area runoff entering the inlet may contain organic carbon, ammonia, nitrates, oil and grease, and heavy metals (ADNR[27]). Alterations of surface and groundwater temperatures, flow rates, and nutrient or oxygen composition can result from mining operations. Mining runoffs into the surrounding Cook Inlet watershed may decrease or contaminate prey fish populations and negatively alter CI beluga critical habitat (Ward et al., 2009).

Pharmaceuticals Pharmaceuticals are biologically active and persistent substances that have been recognized as a continuing threat to environmental stability. The occurrence of pharmaceuticals and their metabolites and transformation products in the environment has become a matter of concern (Fair et al., 2009). These compounds, which may have adverse consequences on living organisms, are extensively and increasingly used in human and veterinary medicine and are released continuously into the environment (Bendz et al., 2005; Nikolaou et al., 2007; Santos et al., 2010). Chronic ecotoxicity data, as well as information on the current distribution levels in different environmental media, continue to be sparse and are focused on those therapeutic classes that are most frequently prescribed and consumed. Studies to determine the presence and significance of pharmaceuticals in CI belugas and their environment have not been conducted.

Emissions Vehicular, train, and aircraft engine warm-up and idle emissions may be a significant source of carbon monoxide pollution in the Anchorage area (Municipality of Anchorage[28]). Emissions may be produced as a byproduct of industrial activities such as coal plant operations, and during aerosolization of various fuels into fumes such as jet fuel. During "break-up" of ice in the spring, air quality warnings are commonly issued due to particles that have accumulated through the winter being emitted from sediment and debris stirred up by vehicular traffic and winds as surface snow melts. Exhaust emissions from marine engines operating in close proximity to killer whales have the potential to degrade air quality and the health of the animals (Lachmuth et al., 2011). However, research is needed to determine if levels of vessel exhaust and air quality over Cook Inlet are comparable or have adverse impacts on belugas.

Produced waters Produced waters, byproducts of oil and gas exploration, are a portion of the oil/gas/water mixture produced from oil wells and are highly saline (3,000 to more than 350,000 mg/L total dissolved solids) (Kharaka and Dorsey, 2005). The characteristics of the produced waters, as well as other discharges described, except drilling muds and cuttings, are based on information obtained during the Cook Inlet Discharge Monitoring Study conducted between 10 April 1988 and 10 April 1989 (EBASCO[29,30]). They may contain toxic metals, organic and inorganic components, radium-226/228, and other naturally occurring radioactive materials that may be water-, air-, or synthetic-based (Kharaka and Dorsey, 2005).

In the oil industry, chemicals are added to the fluids used in drilling processes including water flooding; well work-over, completion, and treatment; and the oil/water separation process. Before being discharged into Cook Inlet, produced waters pass through separators to remove oil. The treatment process removes suspended oil particles from the wastewater, but the effluent contains dissolved hydrocarbons or those held in colloidal suspension (Neff and Douglas[31]). More recent sampling of produced waters has detected no, or very low levels of, hydrocarbon accumulations in Cook Inlet sediments or the water column from produced water discharges (Savoie et al.[17]).

The State of Alaska regulates discharges from offshore platforms, which include drilling muds, drill cuttings, and production waters (the wa-

[27]ADNR. 2011. Alaska Dep. Nat. Resourc., Div. Mining, Land, Water, Mining Resourc. (avail. at http://dnr.alaska.gov/mlw/mining/index.htm), accessed 30 Jan. 2012.

[28]Municipality of Anchorage. 2009. Air quality conformity determination for the 2010-2013 Anchorage Transportation Improvement Program. Prep. by Municipality of Anchorage, Community Planning and Dev. Dep., Transportation Planning Div., and Health and Human Services Dep., Air Qual. Section, Anchorage, Alaska, 34 p. (avail. at http://www.muni.org/Departments/OCPD/Planning/AMATS/Pages/AirQualityandPM10.aspx), accessed 5 Mar. 2012.

[29]EBASCO Environmental. 1990. Summary report: Cook Inlet discharge monitoring study: produced water (discharge number 016) Sept. 1988-Aug. 1989. Prep. for Amoco Production Co., ARCO Alaska Inc., Marathon Oil Co., Phillips Petroleum Co., Shell Western E&P Inc., Texaco Inc., Unocal Corp., Anchorage, Alaska and U.S. Environmental Protection Agency, Region 10, Seattle, Wash.

[30]EBASCO Environmental. 1990. Comprehensive report: Cook Inlet discharge monitoring study: Apr. 1987-Jan. 1990. Prep. for Amoco Production Co., ARCO Alaska Inc., Marathon Oil Co., Phillips Petroleum Co., Shell Western E&P Inc., Texaco Inc., Unocal Corp., Anchorage, Alaska and U.S. Environmental Protection Agency, Region 10, Seattle, Wash.

[31]Neff, J. M., and G. S. Douglas. 1994. Petroleum and hydrocarbons in the water and sediments of upper Cook Inlet, Alaska, near a produced water outfall. Submitted to Marathon Oil Co., Anchorage, AK, by Battelle Ocean Sci. Lab., Duxbury, MA, 30 p.

ter phase of liquids pumped from oil wells). The discharge rate of drill cuttings and drilling fluids during well drilling operations varies, but drill cuttings that are washed of oil contamination, plus a small volume of drilling fluid solids are continuously discharged during drilling operations. This rate varies from approximately 25 to 250 barrels per day into Cook Inlet, which contains several pollutants such as toxic metals and other inorganic and organic compounds (MMS[32]). At the peak of infrastructure development, there were 18 offshore production and 3 onshore treatment facilities, with approximately 368 km (230 miles) of undersea pipelines in upper Cook Inlet (MMS[32]). These products of natural resource exploration and extraction may pose health threats, such as bioaccumulation and toxicity, to beluga whales and their preferred prey and thus warrant further monitoring. While the probability of an impact from chronic, long-term exposure to produced waters on an ecosystem and its attendant populations, such as Cook Inlet and the belugas, is currently considered low, this cannot be substantiated from the relatively low number of published studies in the literature (Neff et al., 2011).

Dredging Dredging activities along coastal waterways have been identified as a concern for the SLE beluga population, where dredging of up to 600,000 m^3 of sediments resulted in the resuspension of contaminants into the water column (DFO[5]). While the volume of dredging in Cook Inlet is comparable to the St. Lawrence estuary (more than 844,000 yd^3 in 2003 at the Port of Anchorage), the sediments in Cook Inlet have not been found to contain harmful levels of contaminants (NMFS[1]); however, these dredged contaminants may bioaccumulate in whales over long periods of time through chronic exposure, causing potential long-term health problems. Furthermore, during dredging operations, contaminants, such as heavy metals and OCs, that settled on the seabed may be stirred up and redistributed into the water column. This potential contaminant release by resuspension may increase their bioaccumulation in whales through the intake of prey items in the vicinity of the work area.

Stormwater and surface runoff Cetaceans may be especially vulnerable to a variety of pollutants and pathogens from runoff. Highway runoff is a significant source of water quality degradation. Various solids, metals, and nutrients present in highway runoff have been identified as inimical to water quality. Particulate matter may transport other pollutants to receiving waters. Heavy metals are known to adsorb to fine particles and other solids, where they may be released when exposed to water and become a threat to aquatic life (Young et al.[33]).

The growing problem of stormwater runoff is related to increases in impervious surface area—streets, parking lots, and buildings—and construction activities that compact the soil. Stormwater runoff may be contaminated with terrestrial fecal pathogens and various water pollutants that are byproducts of urban and suburban activities, such as construction, agricultural chemicals, aircraft and street surface deicing agents (NMFS[1]), automobile use (oil and transmission fluid leakage, brake linings), and lawn care. If left unchecked, the pollutants can further stress fish and other wildlife species that depend on clean water for food and habitat (Miller and Klemens[34]). Despite the potential effects of stormwater on Cook Inlet's ecosystem, there has been little research to determine if stormwater discharge has had a detrimental effect on beluga whales and their prey species.

Vessel Traffic

The majority of Cook Inlet is navigable and utilized by a variety of watercraft that pose a ship strike threat to beluga whales. Ship strikes resulting in mortality of CI belugas have not been definitively confirmed. However, in October 2007, a beluga stranded with evidence of trauma along the right side of the thorax that was suggestive of a ship strike (NMFS[1]).

Various commercial fishing vessels operate throughout the inlet with some areas associated with intensive salmon and herring fishing (NMFS[1]). Ship strikes from large vessels are not expected to pose a significant threat to belugas due to these ships slower speed and straight line movement. Smaller boats that travel at high speed and frequently change directions may pose a greater threat, particularly near river mouths where the belugas often congregate to feed on fish runs. Resulting displacement from sensitive feeding or calving habitats, when avoiding areas of high watercraft traffic, could be detrimental to the recovery of this population. Multiple CI beluga whales have been photographed with external injuries and marks suggestive of vessel strikes (McGuire et al.[8]).

Underwater Noise

Upper Cook Inlet is the most industrialized and urbanized body of water in Alaska, and background noise is relatively high compared to other regions of the state (Blackwell and Greene[35]). Noise from human sources appears to be increasing as more construction and improvement projects are undertaken

[32]MMS. 2003. Cook Inlet planning area oil and gas lease sales 191 and 199, final environmental impact statement. Minerals Manage. Serv., OCS EIS/EA MMS 2003-055, Alaska Outer Continental Shelf (avail. at http://www.mms.gov/alaska/ref/EIS_EA.htm 3), accessed 1 Mar. 2014.

[33]Young, F. C., S. Stein, P. Cole, T. Krarner, and F. Graziano. 1996. Evaluation and management of highway runoff water quality. Fed. Highway Admin., Wash., D.C. (avail. at http://trid.trb.org/view.aspx?id=479031), accessed 6 Oct. 2011.

[34]Miller, N. A., and M. W. Klemens. 2003. Stormwater management and biodiversity: impacts and potential solutions. Fact Sheet, Metropolitan Conserv. Alliance, Wildl. Conserv. Soc., Bronx, N.Y. (avail. at http://eices.columbia.edu/), accessed 2 July 2010.

[35]Blackwell, S. B., and C. R. Greene, Jr. 2002. Acoustic measurements in Cook Inlet, Alaska, during August 2001. Contr. no. 40HANF100123, Greeneridge Rep. 271-1 for NMFS Protect. Resour. Div., Anchorage, Alaska, 41 p. (avail. at NMFS, Alaska Region, 222 W 7th Ave., Box 43, Anchorage, AK, 99513), accessed 21 Oct. 2010.

along with increased vessel and aircraft traffic (NMFS[1]).

Sources of noise in the inlet include marine seismic surveys, aircraft, vessels, pile driving, oil and gas drilling, dredging, military detonations, and shore construction (Moore et al., 2000; Castellote et al., 2011; Lammers et al., 2013), forcing belugas to compete acoustically with natural and anthropogenic noise. Much of upper Cook Inlet is characterized by sand/mud bottoms, shallow depth, and high background noise from currents and tides (Blackwell and Greene[35]), thereby making it a poor acoustical environment.

Wild beluga whales hear best at relatively high frequencies, in the 45–80 kHz, which is above the range of noise from most industrial activities; however, their sensitivity at lower frequencies, where industrial noise concentrates, is still very good (Castellote et al., 2014; Blackwell and Greene[35]). Noise that is above ambient levels and within the same frequency utilized by beluga whales may mask communication between individual whales. Belugas are displaced by loud sources of noise such as ice breakers or marine seismic surveys, often at considerable distances in the tens of kilometers (Finley et al., 1990; Cosens and Dueck, 1993; Miller et al., 2005). More extreme levels of noise exposure can generate physical effects on beluga whales through temporary or permanent damage to hearing capabilities (Richardson et al., 1995).

Acoustic signals that are important for cetacean communication, foraging, predator avoidance, and navigation may be masked by excess high intensity noise in the environment. Commercial shipping associated with the Port of Anchorage and construction projects, increases the levels of background underwater noise (Kruse, 1991; Miller et al., 2000; Foote et al., 2004). Considerable commercial, military, and cargo air traffic increases noise in the Cook Inlet air space from the Anchorage International Airport and the local military base, Joint Base Elmendorf-Richardson.

The base also adds the noise of live fire and explosions due to military exercises, though the base has taken measures to mitigate this effect on beluga at critical areas and times of the year. Chronic noise may affect developmental, reproductive, or immune functions, and cause more generalized stress (Rolland et al., 2012). Some studies show that long-term exposure to anthropogenic noise may cause marine mammals to abandon their essential habitat (Bryant et al., 1984; Morton and Symonds, 2002).

Fish are also considered vulnerable to intense and/or prolonged underwater sounds (Popper and Hastings, 2009). Increased levels of background noise can mask sounds critical to fish survival, decrease auditory sensitivity, modify their behavior, or decrease foraging efficiency as demonstrated in terrestrial species (Siemers and Schaub, 2011).

Land Use and Development

Coastline development along Cook Inlet includes cities and villages with associated ports, airports, roadways, and refineries in close proximity to important beluga habitat. Rather than being uniformly distributed throughout the inlet, the beluga whales are primarily found in nearshore waters. In areas where belugas must compete with humans for the use of nearshore habitats, coastline development may lead to direct loss of habitat or its indirect alteration due to bridges, vessel traffic, noise, and discharges affecting water quality. Salmonids may be impacted by degradation of aquatic ecosystems resulting from land use changes (e.g., agriculture, hydropower, industry, resource extraction, and urban development). The urbanization of land may contribute to local hydrologic problems.

Several port facilities are located in Cook Inlet, the largest located in downtown Anchorage. While most of Knik Arm remains relatively undeveloped, there are several planned or proposed projects that have been identified in a relatively confined portion of lower Knik Arm (Kendall and Cornick, 2015). Knik Arm is an important feeding area for beluga whales during much of the summer and fall, particularly in the upper reaches. The primary concern for beluga whales in this region of upper Cook Inlet is that development may impede their passage through Knik Arm (Kendall and Cornick, 2015).

Health Assessment

To more accurately characterize the effect of anthropogenic and environmental threats to CI beluga whale health, NMFS proposed actions that would contribute to the compilation of disease, pathological, and health indices. One of the actions included developing protocols to collect standardized baseline health data from physical examinations, blood and urine samples, and blowhole and anal swabs, to compare to other beluga populations.

Following the cessation of handling of CI beluga whales, comparative health assessments of wild belugas have been redirected toward more abundant populations (i.e., BB beluga whales) to serve as a control population for Cook Inlet. In 2008, BB beluga whale health assessment studies were initiated to develop safe, reliable, and standardized data collection and sampling protocols and have continued yearly since 2012. This population is considered relatively healthy, with a similar ecological niche (O'Corry-Crowe et al., 1997) as CI beluga whales, and serves as the most suitable surrogate group for health and disease evaluations.

Great potential exists for both observational and theoretical approaches to investigate the processes impeding survival and recovery of CI belugas; however, lack of data is often the key constraint in the application of epidemiological methods. The need for these approaches will inevitably increase in the face of the combined challenges of increasing anthropogenic pressures and climate change.

Many threats facing marine mammals, including CI beluga whales, may be related to the growth, behaviors, and consumption patterns of humans

Table 2.—Summary of key knowledge gaps for potential impediments to Cook Inlet beluga conservation and recovery, and if known, the number of animals, and year, presumed to be associated by each factor to date.

Factor	Knowledge gap(s)
Natural	
Live stranding	• Influence of climate change on water temperature, winds, and cloud cover on beluga adaptations to stranding events are unknown. • Consequences of live-stranding and refloating on long-term survivorship unknown. • Mass live stranding event with associated deaths (1992:2, 1996:5, 1999:5, 2003:5; 2005:1; 2008:2; 2014:2*) (NMFS, Table 5, p. 62 (text footnote 6)). *- 2014 live stranding mortalities suggested by necropsy findings (see Burek-Huntington et al., 2015).
Predation	• Influence on beluga population recovery and growth is not completely understood. • During 11 of 15 observed killer whale-beluga encounters, 17 belugas were injured or killed directly or indirectly through live stranding. One beluga death was assumed in each of remaining 4 encounters for total of 21 deaths during 1985-2002 (Shelden et al., 2003).
Diseases/parasites	
Infectious diseases	• Influence on beluga mortality and reproduction is not completely understood or unknown for pathogens such as *Bartonella* spp., *Brucella* sp., antibiotic resistant bacteria, and non-adapted pathogenic bacteria. • Impact of parasites such *Crassicauda giliakiana* and others on population recovery is unknown or not completely understood. • Necropsy of 38 animals (1998-2013) documented disease as cause of death in 3 cases (Burek-Huntington et al., 2015).
Changes in ice formation	• Long-term impact of increased ice cover and fast ice formation on population survival and recovery unknown.
Freshwater runoff	• Tidal mixing rates within Cook Inlet and link to critical beluga and fish habitat not well understood.
Water temperature	• Areas of the inlet with the strongest upwelling which provide the greatest nutrients for beluga prey species not delineated. • The influences of water temperature and salinity on fish distributions on a small-scale within the inlet are not well defined. • Impact of changes in streamflow and water temperature regimes on anadromous fish survival when in coastal rivers/streams and sound transmission in water.
Anthropogenic	
Pressure on fish stocks	• Salmonid runs: current and historic escapement biomass, species mix and timing for most rivers or watersheds within Cook Inlet not available. • Eulachon: population status, biomass and removal records through fisheries (including subsistence and personal use) and evaluation of fishery impact on belugas through disturbance/harassment or competition. • Other prey species: Distribution, abundance and seasonality within Cook Inlet. • Seasonal beluga prey preferences. • Escapement counts for upper Cook Inlet watersheds. • Stable isotope data on all beluga prey species. • Quantify/update metabolic needs at all beluga life stages.
Non-acoustic vessel disturbance	• Bearing of a given type and level of vessel disturbance on various beluga behaviors. • Relation of behavioral changes to various levels and kinds of disturbance in the Inlet and how it compares to similar populations in Bristol Bay and the St. Lawrence Estuary is unknown. • Amount of leaked/spilled vessel fluids and fuel and potentially toxic cargo into Cook Inlet is unknown as is their impact on beluga health and their prey species. • Does interference from vessels cause significant or permanent behavioral changes? • How does vessel disturbance alter foraging efficiency and energy acquisition? • Does energy expenditure increase in vessel presence?
Roads/vehicular traffic	• Amount of vehicular fluids released onto road surfaces. • Percentage of road runoff that reaches watersheds. • Acoustic/behavioral impact of bridge construction/traffic.
Noise/sound	
Seismic surveys	• Influence of seismic activity on beluga prey fish and invertebrates at all life stages.
Aircraft noise	• Is beluga prey capture affected by vessel noise?
Watercraft noise	• Significance of repeated low-altitude overflights on well-being of cetaceans such as belugas.
Pile-driving	• Bearing of noise from construction and industrial activities.
Explosions/detonations	• What vessels characteristics might most alter beluga behavior (size, speed, and sound-exposure levels)?
Offshore oil/gas drilling	• Detailed delineation of the acoustic environment in Cook Inlet (including historical trends of ambient noise levels).
Cable and pipe-laying	• Characteristics of sound propagation are unknown, particularly under different tide cycles and in the presence of prey. • Critical separation distances from construction activities and ability to partially compensate for masking noise is unknown. • Acoustic responses to sound, including changes in the composition, rates, lengths, and "loudness" of calls. • Effects of human-generated marine noise on beluga prey.
Pollutants (Point-source)	
Municipal waste	• Specific sites within Cook Inlet in need of remediation and cleanup.
Produced waters	• Influence(s) of air pollution on Cook Inlet belugas.
Dredging	• Data describing the fate of pharmaceuticals in the environment is limited.
Mining	• Detailed occurrence and trends of waterborne fecal pathogens is largely unknown.
Pharmaceuticals	• The effects of produced water discharges and dredging operations on beluga prey species are unknown.
Oil spills	
Pathogens	
Pollutants (Nonpoint source)	
Stormwater/surface runoff	• Correlation between contaminants and health effects in belugas is largely unknown.
Groundwater	• Factors influencing contaminant patterns within localized populations of marine mammals such as belugas.
Contaminants	• Influence of chronic oil pollution on beluga whales and other marine mammal species in Cook Inlet (investigate the long-term effects of repeated ingestion of sub-lethal quantities of petroleum hydrocarbons).
Oil spills	• Physical processes that might influence the behavior and trajectory of spilled oil not completely known
Pathogens	
Urban development and habitat loss	• Knowledge about the functional value, stability, and resiliency of many "restored" habitats is incomplete. • The biological effects associated with water management activities are unknown. • Biotic implications of hydrologic alteration in Cook Inlet region are unknown.

(Marine Mammal Commission[36]). Therefore, belugas may be one of the best sentinels for aquatic and coastal environments in northern zones given their long life spans, high trophic level feeding patterns, and extensive fat stores that may serve as depositories for anthropogenic toxins (Reddy et al., 2001), and may allow for a better understanding of the intersection of ecosystem health and the influence of humans on this watershed and the various species that depend on it.

Conclusions

The processes discussed above have varying probabilities of occurrence. Some may be more likely to occur (e.g., fishing pressure from humans)

[36]Marine Mammal Commission. 2004. Annual report to Congress. Mar. Mammal Comm., Bethesda, Md., 167 p. (avail. at http://www.mmc.gov/reports/annual/welcome.shtml), accessed 30 Apr. 2010.

compared to others (e.g., ship strikes). Some events may be more acute (e.g., oil spill, introduced epidemic disease) while others are chronic or long term (e.g., pollution and noise). The relative importance of each impediment to the recovery of Cook Inlet belugas depends not only on its magnitude, but also its duration. Considering these characteristics will aid in determining to which impediments a greater portion of limited research funds should be dedicated. Management may not be able to realistically mitigate the influence of a particular impact, resulting in a relatively larger effect on recovery than a factor that is more readily mitigated. A summary of key gaps in existing knowledge of natural and anthropogenic factors on CI beluga survival and recovery is presented by subcategory in Table 2.

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Behavior and Distribution of Cook Inlet Beluga Whales, *Delphinapterus leucas*, Before and During Pile Driving Activity

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Introduction

Beluga whales, *Delphinapterus leucas*, are found throughout the Arctic and subarctic regions of the Northern Hemisphere, summering in coastal waters and estuaries and wintering in polynyas or in areas of shifting ice (Reeves et al., 2008). Worldwide, there are 29 stocks of beluga whales, but some stock boundaries overlap spatially and seasonally (IWC, 2000). Five stocks of beluga whales exist in U.S. waters (Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay, Cook Inlet). Cook Inlet beluga whales are genetically distinct and geographically isolated from the other stocks (O'Corry-Crowe et al., 1997; Laidre et al., 2000; O'Corry-Crowe et al., 2002).

In 2008, the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) listed the Cook Inlet population as endangered under the U.S. Endangered Species Act (ESA; NOAA, 2008a). The Cook Inlet population was estimated at 312 individuals in 2012 (Hobbs et al., 2015a). The population was expected to increase each year following increased restrictions on subsistence hunting (Hobbs et al., 2015a); however, the population has continued to decline at a rate of approximately 1.6 % per year from 1999–2012 (Hobbs et al., 2015a). According to population modeling studies, an optimal sustainable population should contain no fewer than 780 individuals (NMFS[1]). Extinction risk models show a 42–71% probability of decline and up to a 14% probability of extinction within the next 100 years (Hobbs et al., 2015b).

The "Draft Recovery Plan for the Cook Inlet Beluga Whale (*Delphinapterus leucas*)" (NMFS[1]) includes a review and assessment of the known and possible threats to Cook Inlet belugas. Natural threats include stranding events, predation, parasitism, disease, and environmental changes. Potential anthropogenic threats include subsistence hunting, poaching, fishing, pollution, vessel traffic, tourism and whale watching, coastal zone development, noise, oil and gas development, and scientific research (Norman et al., 2015).

Anthropogenic noise is of particular concern as coastal zone development increases in upper Cook Inlet (Castellote et al., 2011; Norman et al., 2015). Current and proposed development projects include the Knik Arm ferry, the Knik Arm crossing, Chuitna coal mine, ORPC Alaska tidal energy projects, Port MacKenzie expansion, dredging off the Port of Anchorage (POA) to support deep-draft vessels, and the POA Marine Terminal Redevelopment (MTR) Project (NMFS[1,2]).

In-water construction activities at the MTR Project include dredging,

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[1]NMFS. 2015. Draft recovery plan for the Cook Inlet beluga whales (*Delphinapterus leucas*). NOAA, Natl. Mar. Fish. Serv., Alaska Regional Office, Protected Species Division, Juneau. (Avail. online at www.fisheries.noaa.gov/pr/recovery/plans/draft_cib_recovery_plan_15may2015.pdf).

[2]NMFS. 2015. Development projects in Cook Inlet beluga habitat. Cook Inlet beluga whales. (Avail. online at alaskafisheries.noaa.gov/protectedresources/whales/beluga/development.htm, accessed 18 June 2015).

ABSTRACT–Five stocks of beluga whales, Delphinapterus leucas, *exist in U.S. waters. Cook Inlet beluga whales are genetically distinct and geographically isolated from the other stocks and are listed as endangered under the U.S. Endangered Species Act. Many factors are identified as potential threats to Cook Inlet beluga whales, including coastal zone development and anthropogenic noise. The Port of Anchorage Marine Terminal Redevelopment (MTR) Project in Anchorage, Alaska, involves several types of in-water construction including dredging, gravel fill, and pile driving. Pile driving is a major concern because of potential harassment from in-water noise produced by this activity. We investigated beluga whale behavior before (2005–06) and during (2008–09) pile driving activity at the MTR Project. Shore-based visual observations were conducted to document beluga behavior in the presence and absence of pile driving activities. A Pearson's correlation coefficient (2-tailed) was used to examine the relationship between monthly sighting and pile driving rates. Sighting rates, sighting duration, behavior, group size, group composition, and group formation were compared using chi-square goodness-of-fit tests or a Mann-Whitney U test. There was no significant correlation between monthly sighting and pile driving rates; nor was there a significant difference in sighting rates or mean group size. Mean sighting duration was shorter during pile driving (18 ± 3 min vs. 39 ± 6 min). There was also an increase in traveling through the study area relative to other behaviors during pile driving, and an increase in diving with reduced observed feeding. There were significant changes in group composition and increased group dispersion during pile driving. These results suggest that pile driving has potential negative impacts on beluga whales, but whether the impact is long- or short-term is unknown.*

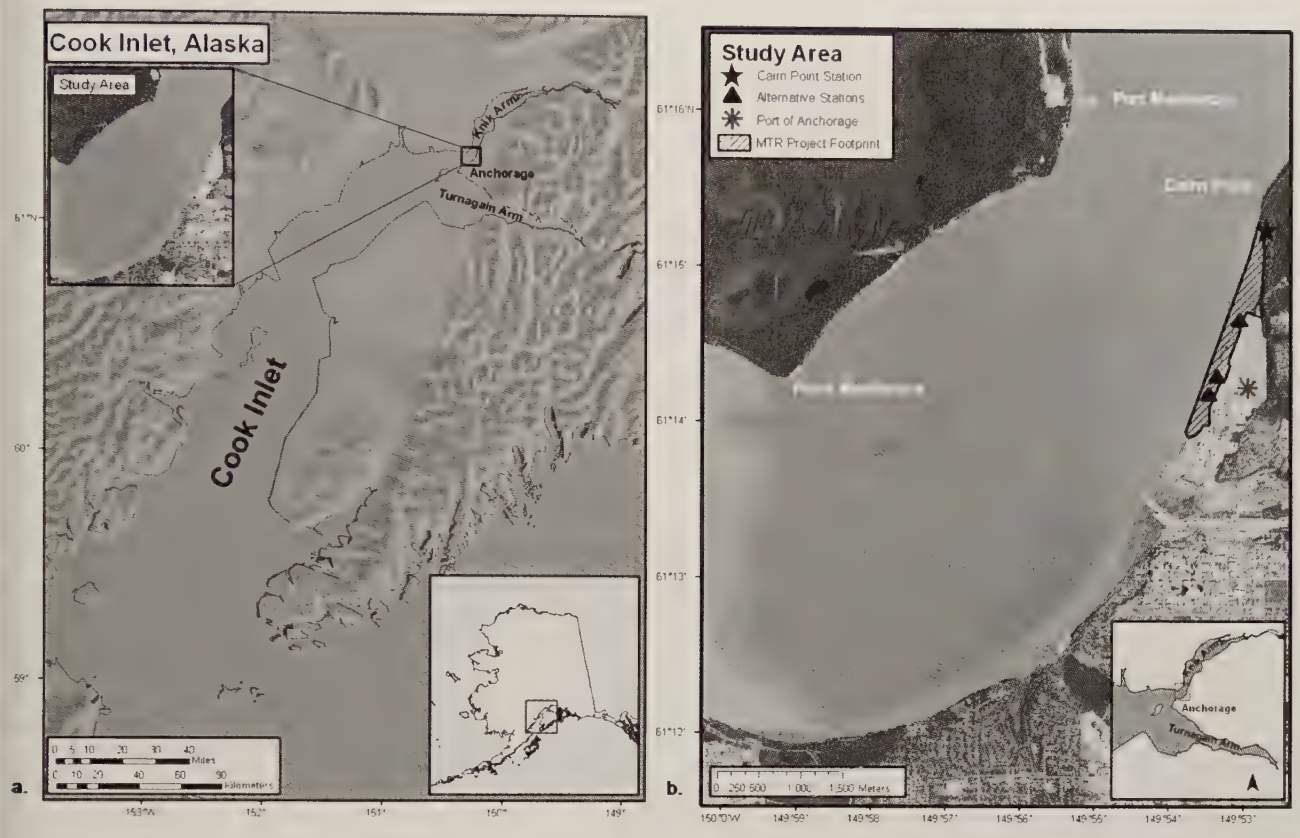

Figure 1.—Cook Inlet, Alaska (a), with an inset of the study area near Anchorage, Alaska. The study area (b) in Knik Arm, upper Cook Inlet adjacent to Anchorage, Alaska. Cairn Point Station (star) is north of Anchorage. The three alternative observation stations, two at the Petroleum, Oil, and Lubricants Towers and one at the northeast corner of the POA dock (triangles) were located at the Port of Anchorage (asterisk) during the 2005—06 seasons. The MTR Project footprint is outlined and crosshatched.

gravel fill, and pile driving (NOAA, 2008b). The combination of these activities could affect beluga whales through an increase in underwater noise, which could interfere with beluga whale communication and echolocation, cause behavioral changes (e.g., increased travel speed, change in dive patterns), mask important sounds, cause avoidance or displacement from important habitat or have a physiological impacts such as impaired auditory senses (Richardson et al. 1995; IWC, 2012).

Studies evaluating impacts of construction activities, such as pile driving, on cetaceans are few (Richardson et al., 1995; Würsig et al., 2000; NRC, 2003; Carstensen et al., 2006; Tougaard et al., 2009; Bailey et al., 2010; Brandt et al., 2011; Dähne et al., 2013; Kendall et al., 2013; Wang et al., 2014), but they demonstrate changes in cetacean behavior. Bailey et al. (2010) showed that pile driving noise can be detected up to 70 km from the source. Responses from Indo-Pacific hump-backed dolphins, *Sousa chinensis* (Würsig et al., 2000; Wang et al., 2014), and harbor porpoises, *Phocoena phocoena*, (Carstensen et al., 2006; Tougaard et al., 2009; Brandt et al., 2011; Dähne et al., 2013), in the presence of pile driving activity include reduced vocal activity and avoidance of the area.

Cook Inlet beluga whale vocal activity also changed in the presence of construction activity (Kendall et al., 2013). Since Cook Inlet beluga whales frequent areas with high levels of construction, it is important to understand how pile driving impacts these whales. We investigated beluga whale behavior before (2005–06) and during (2008–09) pile driving activity at the MTR Project. Sighting rates, mean sighting duration, behavior, mean group size, group composition, and group formation were compared between the two periods. The relationship between beluga whale sighting rates and the rate of pile driving was also examined.

Methods

Study Area

The study area included all visible water from shore-based observation stations located in Knik Arm, upper Cook Inlet near Anchorage, Alaska (Fig. 1a). The POA and Port MacKenzie are both located at the entrance to Knik Arm (Fig. 1b). All observation stations were located on the east side of Knik Arm in the vicinity of the

Table 1.—Summary of sampling effort from 2005–2009.

Year	Observer	Days (d/wk)	Duration (h/d)	Shifts/ day	Seasonal duration	Theodolite	500 x 500 m grid	Effort (h)	Pile driving
2005	Single	2	6	1	2 Aug–28 Nov	Yes	Yes	374.40	No
2006	Single	4	6	1	26 Apr–03 Nov	Yes	Yes	563.80	No
2008	Double	4	4	2	24 Jun–14 Nov	Yes	Yes	611.50	Yes
2009	Double	4	4	2	4 May–18 Nov	Yes	Yes	779.40	Yes

POA (Fig. 1b). The main station was located at Cairn Point on Joint Base Elmendorf Richardson facing south and overlooking the study area.

During 2005–06, three alternative sites were used in addition to the Cairn Point Station (CPS; Fig. 1b). In 2005, two stations at the Petroleum, Oil, and Lubricants Towers (Towers) were used to determine the best vantage point for marine mammal monitoring for the MTR Project (Prevel-Ramos et al.[3]). After the 2005 season, the Towers were no longer used because CPS was determined to be the best location for the study (Prevel-Ramos et al.[3]; Markowitz and McGuire[4]). In 2006, access to CPS was variable; therefore, an alternative station located at the northeast corner of the dock at the POA was occasionally used for observations (Markowitz and McGuire[4]). CPS was the only station used during 2008–09 seasons.

Data Collection

Data for 2005–06 were collected and provided by LGL Alaska Research Associates, Inc. (Prevel-Ramos et al.[3]; Markowitz and McGuire[4]). In 2005, observations were conducted 2 d/wk, 6 h/d, from 2 Aug. to 28 Nov. (Table 1; Prevel-Ramos et al.[3]). Two observers were located at separate stations during daily observational periods; one at CPS and one at the Towers. In 2006, a single observer conducted observations 4 d/wk, 6 h/d from 26 Apr. to 3 Nov. at CPS (Table 1; Markowitz and McGuire[4]). If access to CPS was unavailable, the observer was located at the northeast corner of the dock at the POA.

Twenty minute scan samples were conducted using the naked eye for the first 10 min followed by 10 min of scanning with binoculars (Bushnell[5] 7 x 50 with internal magnetic compass; Funk et al.[6]). Observers used a surveyor's theodolite (tripod mounted Topcon DT-102) to track the location of beluga whale groups. If the theodolite was unavailable, observers used a 500 x 500 m grid overlaying a map of the study area to document the location of whale groups (Prevel-Ramos et al.[3]; Markowitz and McGuire[4]).

During 2008–09, observation effort increased to 4 d/wk, 8 h/d in two shifts of 4 h from 24 Jun. to 14 Nov. 2008 and from 4 May to 18 Nov. 2009 (Table 1). Two observers were located at CPS during all observational periods (Cornick and Kendall[7]; Cornick et al.[8]). During the 2008–09 seasons, protocols were modified to 10-min scan sampling intervals using binoculars (Bushnell 7x50 with internal compass; Nikon Monarch ATB 10x42; Cornick and Kendall[7]; Cornick et al.[8]). One observer tracked whale groups using a surveyor's theodolite (tripod mounted Topcon DT-200) and the other used the 500 x 500 m grid. Observers continued to use the 500 x 500 m grid to maintain consistency in data collection and as a backup if the theodolite was unavailable or not working. For all seasons, daily observation hours were dependent on the available daylight hours.

During all seasons, once a whale group was observed, it was focal-followed until no longer in view (either dove and did not resurface or moved out of the study area) (Altmann, 1974). One focal group was defined as one sighting. Observers documented the location, direction, color class, number of whales, and behavior and movement patterns and noted the time and location of each pattern. Any construction activity was also documented (Funk et al.[6]; Cornick et al.[8]). Descriptive statistics were calculated for sampling effort to determine monthly and annual totals. Numbers of sightings were calculated by month and year (Table 2).

Theodolite tracking was used to triangulate the location of whale groups by measuring the horizontal angles from a selected reference point and vertical angles relative to the axis of gravity (Würsig et al., 1991; Gailey and Ortega-Ortiz, 2000). The height of the eyepiece (measured daily), the vertical height of the station (surveyed at 62 m above mean lower low water [MLLW]) and tide levels (height from MLLW) were also used to calculate the position of the whale group. Once the horizontal and vertical angles, the height of the station, and the tide height were known, each group's

[3]Prevel-Ramos, A., T. M. Markowitz, D. W. Funk, and M. R. Link. 2006. Monitoring beluga whales at the Port of Anchorage: pre-expansion observations, August–November, 2005. Rep. LGL Alaska Res. Assoc., Anchorage, for Integrated Concepts Res. Corp. Port of Anchorage, and U.S. Dep. Transp. Marit. Admin., 30 p.

[4]Markowitz, T. M., and T. J. McGuire. 2007. Temporal-spatial distribution, movements and behavior of beluga whales at the Port of Anchorage, Alaska. Rep. LGL Alaska Res. Assoc., Inc., Anchorage, for Integrated Concepts Res. Corp. and the U.S. Dep. Transportation Marit. Admin., 93 p.

[5]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[6]Funk, D. W., T. M. Markowitz, and R. Rodrigues. 2005. Baseline studies of beluga whale habitat use in Knik Arm, Upper Cook Inlet, Alaska: July 2004–July 2005. Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, in assoc. with HDR Alaska, Inc., Anchorage, for the Knik Arm Bridge and Toll Authority, Anchorage, Dep.Transportation Public Facil., Anchorage, and Fed. Highway Admin., Juneau, 217 p.

[7]Cornick, L. A. and L. S. Kendall. 2008. Distribution, habitat use and behavior of Cook Inlet beluga whales and other marine mammals at the Port of Anchorage Marine Terminal Redevelopment Project June–November, 2008. Rep. prep. for U.S. Dep. Trans. Marit. Admin., Port of Anchorage, and Integrated Concepts and Res. Corp. by Alaska Pac. Univ., Anchorage, p. 27.

[8]Cornick, L. A., L. S. Kendall, and L. C. Pinney. 2010. Distribution, habitat use and behavior of the Cook Inlet beluga whales and other marine mammals at the Port of Anchorage Marine Terminal Redevelopment Project, May–November 2009. Sci. Mar. Mammal Monitoring Program, 2009 Ann. Rep. prep. for U.S. Dep. Transportation Maritime Admin., Port of Anchorage, and Integrated Concepts and Res. Corp. by Alaska Pac. Univer., Anchorage, p. 38.

Table 2.—Sampling effort and sightings from 2005–2009.

Month	Sampling effort		Sightings		
	Days	Hours	No. of days whales sighted	No. of whales	No. of groups
2005					
August	14	83.10	4	41	4
September	16	96.10	6	51	10
October	12	96.10	2	7	2
November	9	99.10	2	57	7
Total	51	374.40	14	156	23
2006					
April	2	12.00	1	2	2
May	10	60.00	3	7	3
June	18	108.00	3	8	4
July	14	84.00	2	2	2
August	16	92.10	4	35	6
September	16	96.00	6	26	7
October	16	96.00	2	2	2
November	3	15.70	0	0	0
Total	95	563.80	21	82	26
2008					
June	4	27.67	0	0	0
July	19	150.17	0	0	0
August	17	120.50	9	126	32
September	19	133.83	6	57	22
October	22	128.00	2	13	5
November	10	51.33	3	87	15
Total	91	611.50	20	283	74
2009					
May	15	96.00	3	33	15
June	18	144.00	0	0	0
July	18	126.00	0	0	0
August	17	130.40	5	67	22
September	16	121.50	4	35	12
October	18	113.00	0	0	0
November	10	48.50	2	31	5
Total	112	779.40	14	166	54
Overall Total	349	2,329.10	69	687	177

Table 3.—Definitions of focal group behavior and potential acute responses to noise.

Focal group behavior[1]	Description
Traveling	Observation of swimming in one direction without stopping
Diving	Observation of a full back arch or fluke up
Milling	Observation of staying in one location in no particular order
Resting	Observation of motionless on the surface of the water
Observed feeding	Observation of catching prey (e.g., fish) in the mouth
Suspected feeding	Diving must be primary activity, then observation of chasing prey, diving near-shore or in an area known to have prey species (e.g., Ship Creek)
Other	Observation of other behavior worth noting such as spy hopping (i.e., a whale observed in a vertical position with its head extending out of the water), etc.
Acute response[2]	**Description**
Startled effect	A whale group appears to be suddenly disturbed or agitated
Approaches and then leaves the area	A whale group moves toward the area and then change direction and leave the same way they entered
Change in swimming speed	The increase or decrease in the speed of a whale group
Abrupt change in direction	A whale group suddenly changes the direction they are traveling
Abrupt dives	A whale group suddenly alters their diving pattern to more quick dives
Disperse	A whale group suddenly breaks apart and moves in separate directions
Other	A behavior other than the ones described above. Describe the behavior in the comments column.

[1]Mann, 2000.
[2]Ljungblad et al., 1988; Würsig et al., 2000; Patenaude et al., 2002

position was translated into x/y map coordinates.

The theodolite was connected to a Dell laptop computer with an RS-232 cable. Data were collected, organized, and beluga whale locations were calculated using Pythagoras tracking software (http://www.tamug.edu/mmbeg/pythagoras.htm). Station parameters and tide height were entered into Pythagoras prior to observations. Tide heights were generated with JTides 4.7 and 5.2 software (http://www.arachnoid.com/JTides) from the Anchorage (Knik Arm), Alaska station. Tracking data were stored in Microsoft Access for Windows. Only theodolite tracking data from CPS were used in statistical analysis.

Focal group behavior (Mann, 2000) and swimming formation were continuously sampled (Table 3). Milling was not included as a behavioral state during 2005–06; it was added to the list of behavioral states in 2008. Potential indicators of negative responses to noise were documented, if observed.

Group size and composition were recorded continuously until the whales went out of view. As whale groups were tracked through the study area, the number of individuals within each group was recorded multiple times. Once the whale group went out of view, the most accurate count was documented and used for group size statistical analysis. Each group was then classified into size categories (lone, 2–5, 6–10, 11–25, 26–50, >50). Group composition was defined by color class (white, grey, or mixed). Lone individuals of unknown color were excluded only from the group composition analysis ($n = 3$).

In 2009 beluga whales were classified by color because more recent data have suggested that color cannot be used reliably to determine age class in beluga whales (McGuire et al.[9]). Therefore, age classes documented

[9]McGuire, T. L., C. C. Kaplan, M. K. Blees, and M. R. Link. 2008. Photo-identification of beluga whales in Upper Cook Inlet, Alaska. 2007 Annu. Rep. prep. by LGL Alaska Res. Assoc., Inc., Anchorage, for Chevron, Nat. Fish Wild. Found., and ConocoPhillips Alaska, Inc., 52 p.

from 2005 to 2008 were reclassified into color classes as white (previously coded adults), grey (subadults), and dark grey in close proximity of another whale (calf). Animals during this period that were classified as unknown were not reclassified.

Group formation was categorized as densely packed, dispersed, or alone. Group formation was not documented in 2006; therefore, group spread data (defined as body lengths apart) were recoded to match subsequent years' classifications. Group spread included ≤ 3 body lengths apart (densely packed), ≥ 4 body lengths apart (dispersed), and one individual (alone). If spread was not described, no group formation was assigned, and that sighting was not used in group formation analysis.

Data from 2005–06 were classified as before pile driving activity and from 2008–09 were classified as during pile driving activity. In 2005 and 2006, no in-water pile driving took place at the MTR Project. Data from 2007 were excluded from the analysis due to an abbreviated field season (~ 1.5 months).

Regular in-water pile driving began on 24 July 2008 and continued through the end of 2009. Documentation of in-water pile driving began on 1 Aug. 2008. Other in-water construction activities (e.g., dredging and fill placement) also took place from 2005 to 2009.

In 2005–06, general construction activities were noted (Prevel-Ramos et al.[3]; Markowitz and McGuire[4]) and for 2008–09, the specific type and duration of construction activity were recorded. Construction activities often occurred simultaneously; therefore, construction activities were grouped into categories: pile driving (i.e., impact pile driving [IPD], vibratory pile driving [VPD]), and no pile driving (i.e., dredging, fill placement, other).

The MTR Project environmental consulting firm Integrated Concepts and Research Corporation (ICRC) provided data on the total number of hours of pile driving for each year. Because not all months of pile driving activity were broken down into daily events, monthly pile driving activity was used in the statistical analysis. Construction records were normalized to sampling effort. For example, beluga whales were monitored during 17 days in August 2008; therefore, construction activity from those 17 days was used in the statistical analysis.

Statistical Analysis

Monthly in-water pile driving rates at the MTR Project for each year of construction were compared to monthly sighting rates using Pearson's correlation coefficient (2-tailed). Pile driving rates were calculated by dividing the monthly number of hours of pile driving activity that occurred on monitoring days by the monthly sampling effort. Sighting rates were determined by dividing the monthly number of sightings by the monthly sampling effort. Distributions for beluga whale sighting rates, sighting duration, and group size were heavily skewed and were not improved by transformation; therefore, Mann-Whitney U tests were also used to compare these variables before and during pile driving.

Chi-square goodness-of-fit tests were used to compare behavior, group composition, and group formation before and during pile driving. Sampling effort increased from 2005 to 2009, resulting in unequal sample sizes; therefore, expected values for the chi-square tests were proportionally adjusted to correct for the difference in effort. Alpha levels for all analyses were set at $p < 0.05$ and all values are reported as mean ± 1 standard error unless otherwise indicated. SPSS (v. 15.0 for Windows) was used for statistical analyses.

Results

A total of about 2,329 h of sampling effort was completed across 349 d from 2005 to 2009 (Table 2). Overall, 687 whales in 177 groups were documented during the 69 d that whales were sighted (Table 2). A total of about 353 and 1,663 h of pile driving activity took place in 2008 and 2009, respectively. There was no relationship between monthly beluga whale sighting rates and monthly pile driving rates ($r = 0.19$, $p = 0.37$).

Sighting rates before ($n = 12$; 0.06 ± 0.01) and during ($n = 13$; 0.01 ± 0.03) pile driving activity were not significantly different ($U_{std} = .412$, $p = 0.68$). However, sighting duration of beluga whales decreased significantly ($U_{std} = -3.733$, $p < 0.001$) during pile driving (39 ± 6 min before and 18 ± 3 min during; Fig. 2).

There were also significant differences ($\chi^2_{(2)} = 22.80$, $p < 0.01$) in behavior before vs. during pile driving (Fig. 3). Beluga whales primarily traveled through the study area both before and during pile driving; however, traveling increased relative to other behaviors during pile driving activity. Diving ($n = 18$ and $n = 22$, respectively) increased while suspected feeding ($n = 6$ and $n = 4$, respectively) decreased during pile driving. Feeding was observed on two occasions before pile driving and on zero occasions during pile driving. Documentation of milling began in 2008 and was observed on 21 occasions. No acute behavioral responses were documented.

Mean group size decreased during pile driving (5 ± 1 before and 4 ± 0 during); however, this difference was not statistically significant ($U_{std} = -.959$, $p = .34$). There were significant differences in group composition before and during pile driving ($\chi^2_{(6)} = 60.09$, $p < 0.01$; Fig. 4; Table 4). Substantial differences in group composition before and during pile driving occurred among lone grey belugas (11% and 2%, respectively), lone white belugas (19% and 24%, respectively), groups with 2–5 whites (13% and 35%, respectively), mixed groups of 6–10 individuals (15% and 7%, respectively), and mixed groups of 11–25 individuals (15% and 4%, respectively; Table 4). Only one group of 26–50 mixed ($n = 33$, 1%) was observed in the study area during pile driving activity. No groups > 50 were observed.

Differences in group composition were also reflected in significant differences in group formation ($\chi^2_{(2)} =$

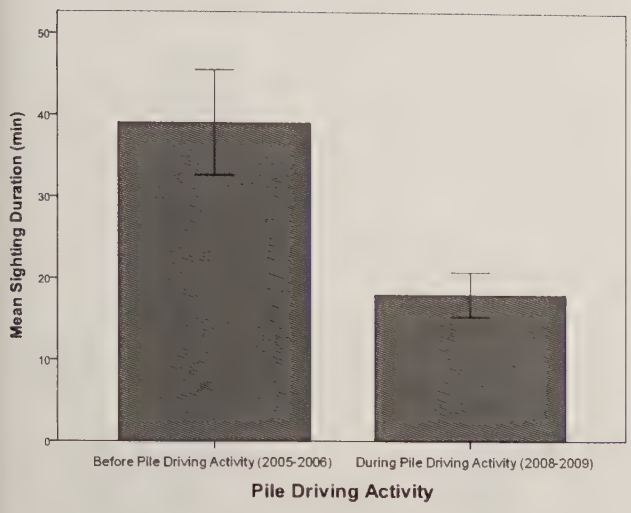

Figure 2.—Mean sighting duration of beluga whales decreased significantly during pile driving (39 ± 6 min before; 18 ± 3 min during; $U_{std} = -3.733$, $p < 0.001$).

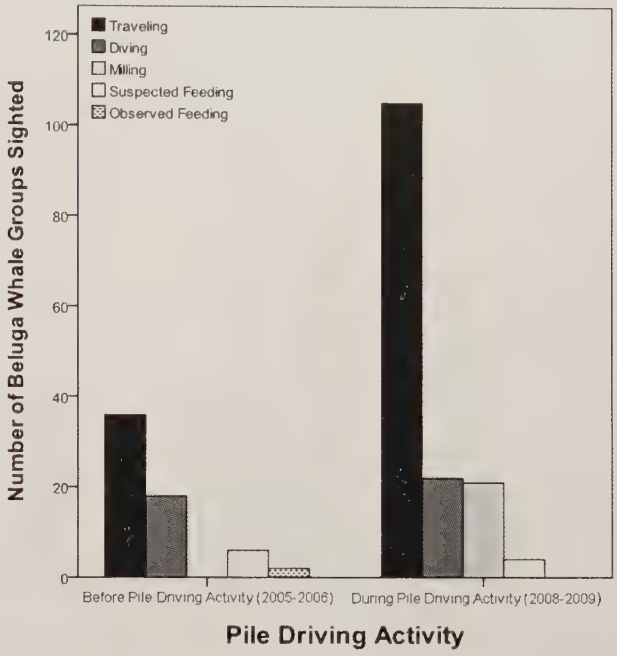

Figure 3.—Beluga whale behavior before and during pile driving. Behavior was significantly different before and during pile driving ($\chi^2_{(2)} = 22.80$, $p < 0.01$). Beluga whales primarily traveled through the study area both before and during pile driving; however, traveling increased during pile driving. Diving increased while suspected feeding decreased. Observed feeding was only observed before pile driving. Documentation of milling began in 2008 and was observed on 21 occasions. No acute behavioral responses were documented.

7.75, $p = 0.02$) before and during pile driving (Fig. 5). Beluga whales were primarily observed densely packed before and during pile driving activity ($n = 23$ and $n = 70$, respectively); however, the number of dispersed groups increased during pile driving ($n = 4$ before and $n = 21$ during), as did observations of lone individuals ($n = 13$ before and $n = 32$ during).

Discussion

Although there were no significant differences in beluga whale sighting rates during pile driving, and monthly pile driving rates were not correlated with monthly sighting rates, significant differences in sighting duration, behavior, and group structure were observed during in-water pile driving at the MTR Project. Beluga whales are highly social animals that rely heavily on acoustic signals for communication and socializing, prey detection, and predator avoidance (Richardson et al., 1995). Therefore, even subtle changes in the acoustic profile of the environment may disrupt important activities, and thus impact the population.

Table 4.—Beluga whale group composition (%) before and during pile driving.

Group composition	Before pile driving (%)	During pile driving (%)
Lone white	19	24
Lone grey	11	2
2–5 mixed	26	24
2–5 white	13	35
6–10 mixed	15	7
6–10 white	2	2
11–25 mixed	15	4
11–25 white	0	0
26–50 mixed	0	1
26–50 white	0	0
> 50 mixed	0	0
> 50 white	0	0

The combination of a ~54% reduction in sighting duration (Fig. 2) and a 64% increase in traveling behavior (Fig. 3) suggests that beluga whales altered their movement patterns during pile driving. Temporary avoidance and even abandonment of areas during pile driving has been observed in Indo-Pacific hump-backed dolphins (Würsig et al., 2000; Wang et al., 2014) and harbor porpoise (Carstensen et al., 2006; Brandt et al., 2011, Dähne et al., 2013). In some cases the animals returned to the area once pile driving activity was completed (Wursig et al., 2000; Carstensen et al., 2006); however, the return time occasionally took several days (Carstensen et al., 2006).

Brandt et al. (2011) observed the reduction of harbor porpoise activity and density in construction areas over the entire 5 mo period that pile driving took place. They also documented increased use of areas as far as 22 km away from the construction site. Dähne et al., (2013) documented a similar avoidance response from harbor porpoise at distances 20 km or greater from the source. Würsig et al. (2000) observed a doubling of swim speeds of Indo-Pacific hump-backed dolphins during pile driving. Tougaard et al. (2009) observed changes in harbor porpoise vocal behavior beyond distances of 20 km. Wang et al. (2014) suggested that Indo-Pacific

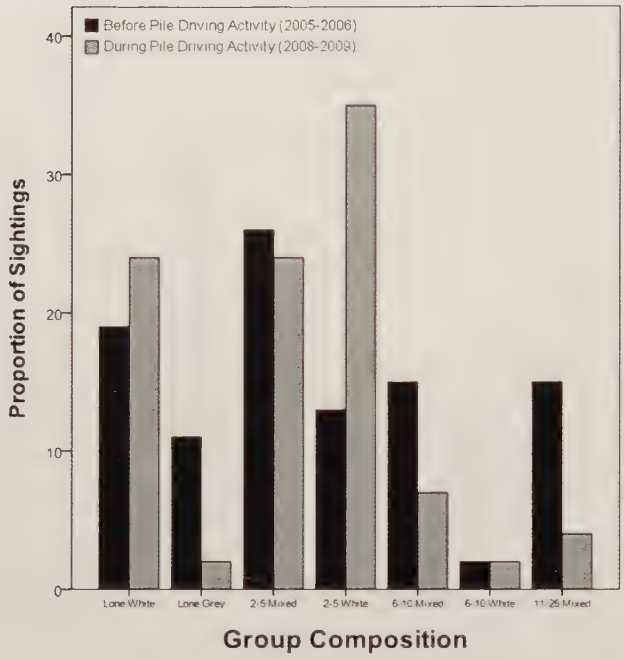

Figure 4.—Beluga whale group composition before and during pile driving activity. Group composition was significantly different before and during pile driving ($\chi^2_{(6)}$ = 60.09, $p < 0.01$).

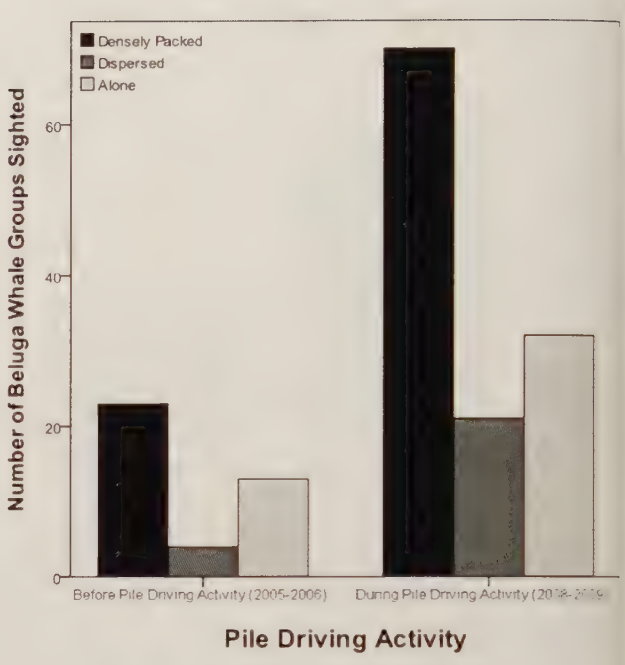

Figure 5.—Beluga whale group formation before and during pile driving. Group formation was significantly different before and during pile driving ($\chi^2_{(2)}$ = 7.75, p = 0.02). Beluga whales were primarily observed densely packed both before and during pile driving (n = 23 and n = 70, respectively). Dispersed groups (n = 4 and n = 21, respectively) and lone individuals (n = 13 and n = 32, respectively) increased during pile driving.

hump-backed dolphin's clicks would not be adversely affected during pile driving; however, their whistles would likely be masked. Kendall et al. (2013) only recorded echolocation clicks and no whistles or noisy vocalizations near construction activity during an acoustic study at the MTR Project, which is unusual for this highly vocal species (Reeves et al., 2008). The lack of whistles and noisy vocalizations and the presence of echolocation clicks correspond to the travel behavior observed in this study because echolocation clicks are generally associated with navigation and foraging (Au et al., 1985; Au et al., 1987; Faucher, 1988; Turl and Penner, 1989; Turl, 1990). However, Kendall et al. (2013) observed a higher click rate without construction activity indicating potential disturbance with a possible reduction in vocal activity during construction. Because pile driving can be detected at distances up to 70 km (Bailey et al, 2010) and beluga whales can likely hear pile driving activity over great distances from the source (Erbe and Farmer, 2000), belugas entering Knik Arm may alter their travel patterns through the area and maximize their distance from the source to avoid prolonged exposure to noise associated with pile driving.

Observations of increased diving but reduced suspected/confirmed feeding may suggest disruptions to foraging patterns; however, few observations of suspected and confirmed feeding were documented during this study (10 suspected and 2 confirmed). Beluga whales feed at locations close to the MTR Project (e.g., Ship Creek). With increased noise associated with pile driving, beluga whales may reduce their vocal activity (Kendall et al., 2013), resulting in increased dive frequency but reduced capture success. The change in foraging behavior combined with the increased traveling suggests that during pile driving, beluga whales are choosing to move past these areas to other, potentially richer, feeding areas further into Knik Arm (e.g., Six Mile Creek, Eagle River, Eklutna River). These locations contain predictable salmon runs (ADFG, 2010), an important food source for Cook Inlet beluga whales (NMFS[1]), and the timing of these runs has been correlated with beluga whale movements into the upper reaches of Knik Arm (Ezer et al., 2013).

Mean group size was reduced during pile driving, although this difference was not statistically significant. The trend is supported, however, by the significant increase in the number of lone white whales and the decrease in size of mixed groups from primarily 6 or more animals to groups of 2–5 animals (Fig. 4). Beluga whales in densely packed groups increased by ~67% during pile driving (Fig. 5); however, there were also significant

increases in dispersed groups (~81%) and lone white whales (~60%). Given that mixed groups were smaller, it may be that these groups contained calves, and the densely packed formation provided decreased distances for communication in a noisier environment and better protection for calves. This is supported by the significant decrease in the number of lone grey animals (Fig. 4) and previous data that indicate that Knik Arm is potentially a nursery area (Huntington, 2000; Hobbs et al., 2015c).

The shallow waters of Knik Arm may also provide protection from killer whale, *Orcinus orca*, predation on calves (Shelden et al., 2003). Conversely, the increase in dispersed groups is reflective of the increase in the number of lone white whales and the number of small groups (2–5 individuals) of all white whales. Caron and Smith (1990) suggest summer segregation of the sexes; therefore, these dispersed groups of all white animals may be older juvenile and adult males, which likely reduces the need to travel more tightly spaced.

Group living is beneficial because it decreases an animal's susceptibility to predation and decreases their risks from environmental challenges (i.e., decreases their cost of locomotion; Connor, 2000). Bowhead, *Balaena mysticetus*; sperm, *Physter macrocephalus*; and beluga whales have been observed forming densely packed groups in the presence of anthropogenic noise (e.g., seismic airgun blasts, water- and aircraft; Ljungblad et al., 1988, Blane and Jaakson, 1994; Patenaude et al., 2002; Smultea et al., 2007). Smultea et al. (2007) interpreted this response by sperm whales near the main Hawaiian Islands as a predator defense response. The overall reduction in group size and increase in the number of animals in more dispersed groups in the present study may reduce this benefit for Cook Inlet beluga whales during pile driving.

The Cook Inlet beluga whale's range has contracted over the last three decades to the upper reaches of Cook Inlet, and the current population center is just outside the mouth of Knik Arm off the coast of Anchorage (Rugh et al., 2010; Shelden et al., 2015). Knik Arm is designated as Type I Critical Habitat for this population (NOAA, 2011). The area north of the construction site is an important foraging area (Sixmile Creek and Eagle River; Hobbs et al., 2005) and may also serve as a calving and nursery area (Huntington, 2000; Hobbs et al., 2015c).

Any avoidance of Knik Arm could cause permanent displacement from critical habitat, potentially reducing foraging and reproductive success and hindering recovery. Continued monitoring of Cook Inlet beluga whales both during the completion of the MTR Project and well after construction is completed is necessary to determine if there are long-term impacts on Cook Inlet beluga whales, or if the observed changes in movement and association patterns and behavior are a temporary acute stressor on the population during pile driving events. Additionally, other development projects that increase noise levels in Cook Inlet should continue to collect and share data with the scientific community. These data can be compiled and used to determine the cumulative effects of noise and whether noise from development projects is creating long- or short-term impacts on the population, which is currently unknown.

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Cook Inlet Beluga Whale, *Delphinapterus leucas*, Observations near Anchorage, Alaska Between 2008 and 2011: Results from a Citizen Scientist Project

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Introduction

The endangered Cook Inlet beluga whale, *Delphinapterus leucas*, frequents the waters of the Anchorage Coastal Wildlife Refuge (ACWR) and has often been seen by observant local residents feeding near the Campbell Creek estuary (Carlson[1]). Belugas spend much of their time when the inlet is ice-free in relatively shallow waters near rivers in upper Cook Inlet where prey availability is high and the risk of predators is low (Moore et al., 2000). The proximity of the refuge to Anchorage, Alaska's largest city, increases use of the refuge and its natural resources for both public education and recreational enjoyment, making them vulnerable to human impact. Cook Inlet belugas have a tendency toward site fidelity in summer (Rugh et al., 2010), and with perilously low population numbers, this stock is at risk for loss of genetic diversity, which may impact the health of the species (Hobbs et al., 2015a; O'Corry-Crowe et al.[2, 3]).

Friends of the Anchorage Coastal Wildlife Refuge (FAR) is a 501(c)(3) nonprofit organization of citizens and professionals whose mission is "To preserve the integrity and biological diversity of the Anchorage Coastal Wildlife Refuge." Many mammals, fish, one amphibian, numerous species of invertebrates, and at least 220 species of birds visit or live in or near the ACWR. This refuge is part of a recognized Important Bird Area (IBA) of continental importance (National Audubon Society[4]). The refuge hosts a wide variety of flora providing for specific habitat requirements of wildlife (ADFG[5]). FAR believes that more collaboration between all researchers and resource managers will be useful in compiling data on vulnerable species, with the hope that the amassed information will help guide coastal

[1]Carlson, B. S. Friends of the Anchorage Coastal Wildlife Refuge (FAR), Alaska. Personal commun., 2011.

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[2]O'Corry-Crowe, G. M., C. Bonin, and A. Frey. 2007. Molecular genetic analysis of population structure, dispersal and gene flow of beluga whales, *Delphinapterus leucas*, in the western nearctic: new findings on the Cook Inlet population. Unpubl. rep. to Natl. Mar. Fish. Serv., Alaska Reg. Off., 25 p. Avail. from NMFS Alaska Reg. Off., Off. Protected Resour., 709 West 9th Street, Juneau, AK 99802-1668.

[3]O'Corry-Crowe, G. M., R. S. Suydam, R. Hobbs, L. Quakenbush, and B. Mahoney. 2008. Molecular genetic analysis of population structure, dispersal and gene flow of beluga whales, *Delphinapterus leucas*, in the western nearctic: new findings on the Cook Inlet population. *In* Alaska Mar. Sci. Symp., Jan. 20-23, 2008, Anchorage, AK, p. 136. (Retrieved 15 Mar. 2012 from http://doc.nprb.org/web/symposium/2008/Abstract%20Book%202008.pdf).

[4]National Audubon Society 2012. Important bird areas in the U.S. (accessed 11 Apr. 2012 from http://web4.audubon.org/bird/iba/).

[5]ADFG. 1991. Anchorage Coastal Wildlife Refuge Management Plan. Prep. by Div. Habitat Wildl. Conserv., 333 Raspberry Road, Anchorage, AK 99518-1599. (Avail. online at https://www.adfg.alaska.gov/static/lands/protectedareas/_management_plans/anch_coastal_management_plan.pdf).

ABSTRACT—The Anchorage Coastal Beluga Survey (ACBS) is an independent survey effort staffed by trained citizen scientists. It was developed and run by Friends of the Anchorage Coastal Wildlife Refuge (FAR), in collaboration with the NMFS Alaska Regional Office, National Marine Mammal Laboratory, Defenders of Wildlife, and the Alaska Center for the Environment. After consulting with key biologists, the survey was designed to help fill data gaps by prioritizing needs according to desired information, available resources, and selecting appropriate shore-based sites. Survey goals were to document the presence, absence, color, numbers, and behavior of beluga whales, Delphinapterus leucas, *and to create an archival record of beluga observations along the coast of Anchorage. Trained volunteers recorded information during daylight hours of ice-free months between 2008 and 2011, counting the number of whales in groups during survey shifts and did not identify individual belugas, so individuals were likely observed multiple times within and across seasons. Over 4 years and a total of 444 observation hours, the ACBS project documented 77 groups of belugas with a total of 507 beluga whale sightings, of which 31 included calves. Opportunistic reports made by ACBS volunteers during non-survey hours included an additional 29 groups of belugas with a total of 101 whales sighted, of which 12 sightings included calves. Volunteers documented the greatest number of sightings when FAR scheduled the survey to coincide with predicted fish runs and higher tides. During this scheduled survey the only other land-based beluga documentation projects in the given areas were a required observer project near Ship Creek for the Port of Anchorage work and, between August–November 2011 and April–July 2012, the Point Campbell overlook project for Cook Inlet Regional Incorporated's potential development of Fire Island. NMFS Alaska Regional Office has utilized the data and ACBS project information during permitting activities in the Anchorage area. This survey has helped increase public awareness and education and provided citizens with unique opportunities to actively contribute to the base of knowledge about Cook Inlet beluga whales.*

resource development and positively impact the recovery of the Cook Inlet beluga stock.

Between 2000 and 2012, FAR volunteers reported or helped with the logistics and labor regarding 26 dead marine mammals, most of which were beluga whales, washed up in the ACWR. In 2006, after 6 years of finding dead beluga whales stranded in the ACWR, FAR initiated a volunteer beluga monitoring study to document the presence of belugas along the Anchorage coastline and to provide scheduled scanning for strandings. The Anchorage Coastal Beluga Survey (ACBS, also referred to as "the survey") was developed as an independent land-based project staffed by trained citizen scientists. The survey was an outgrowth of relevant local knowledge and concern for Cook Inlet belugas shared by Anchorage residents based on their observations over the decade preceding the survey.

"Citizen Science" has been defined as nonprofessional persons engaging in scientific investigation that may be either hypothesis-driven, monitoring to be later used to test a hypothesis, or observations on natural history (Miller-Rushing et al., 2012). FAR volunteers, some of whom assisted National Marine Fisheries Service (NMFS) enforcement investigations, necropsies, and salvage for educational and scientific purposes, welcomed the formation of the survey. Citizen science programs such as the North American Breeding Bird Survey, North American Bird Phenology Program (part of the USA National Phenology Network), the U.S. National Weather Service's Cooperative Observer Program, and Izaak Walton League's Save Our Streams (water quality monitoring) have successfully collected data for use by professional scientists and used to shape policy and management decisions (Miller-Rushing et al., 2012). For survey volunteers, the opportunity to gather data that might contribute to policy decisions was important considering the Cook Inlet beluga was listed as "endangered" the year the survey began. Citizen science allows the use of more types of information for political decision-making and increases the opportunity for many perspectives to add their efforts to the collection of data for the support of policy decisions. (Freitag and Pfeffer, 2013).

The ACBS is a "co-created" collaborative citizen science project designed by interested FAR volunteers, with input from beluga and other scientists, to be conducted by public volunteers (Bonney et al.[6]). The data collected during the survey were chosen based on feedback FAR received from researchers and policy makers who wanted to fill data gaps on presence and absence of Cook Inlet belugas in coastal waters. The goals of FAR's survey were to monitor and document beluga activity in Anchorage coastal waters and to share the resulting information with NMFS, Alaska Department of Fish and Game (ADFG), and other parties interested in the science and well-being of Cook Inlet belugas. The survey gathered information on the occurrence, color, numbers, and behavior of belugas along the Anchorage coast, and created an archive of data for reference purposes.

As one objective supporting the goals, FAR also wanted to increase awareness of, and education about, Cook Inlet belugas and their habitat through educating volunteers who would then do public outreach. FAR knew that the presence of wildlife documentation crews posted along the coast would increase interest and curiosity about belugas by the public and believed that it would also make citizens more willing to consider how the actions of ordinary people might help enable this endangered population to recover. With trained citizen scientists on site collecting data and sharing information with other citizens to increase awareness, it was believed that the survey could also promote stewardship of the Cook Inlet beluga and the habitat upon which they depend. FAR's shared outreach highlighted specific actions, such as supporting clean waterways, avoiding motor boating near belugas, or paying more taxes for better waste water treatment, hoping that if citizens were more cognizant of the plight of the beluga they would be more willing to do what they could to help affect positive change. Finally, although the survey was designed to document real-time beluga sightings, an additional objective was training observers to scan for and report any live or dead strandings of marine mammals during scheduled shifts, thus providing oversight of these survey locations during the project.

In addition to sightings data collected, the survey database included incidental sightings reported by volunteers and the public that occurred outside of scheduled survey shifts. This paper covers the basic methods and results of the ACBS from 2008 through 2011.

Methods

Survey Sites

Survey sites were selected based on Cook Inlet beluga data desired by research and management institutions, usefulness in helping meet project objectives, relevance to the lead organization's mission, and personnel available to meet staffing needs for each. Of 27 initial possible survey sites, 9 were selected. An additional 3 supplemental sites were selected to collect desired data, for a total of 12 sites. FAR also collected data from more than 20 localities of incidental sightings; some were project sites (between survey sites or off-survey time) and others were simply places where informants observed belugas and reported them to FAR. Figure 1 shows a list of dedicated and supplemental ACBS sites. Some sites were selected based on their proximity to creeks or rivers expected to draw belugas (Fig. 2). When developing a model for habitat use in a marine ecosystem, belugas

[6]Bonney, R., H. Ballard, R. Jordan, E. McCallie, T. Phillips, J. Shirk, and C. Wilderman. 2009. Public participation in scientific research: defining the field and assessing its potential for informal science education. A CAISE inquiry group report. Wash., D.C., Cent. Advance. Informal Sci. Educ. (CAISE). (Retrieved April 2014 from http://informalscience.org/images/research/PublicParticipationinScientificResearch.pdf).

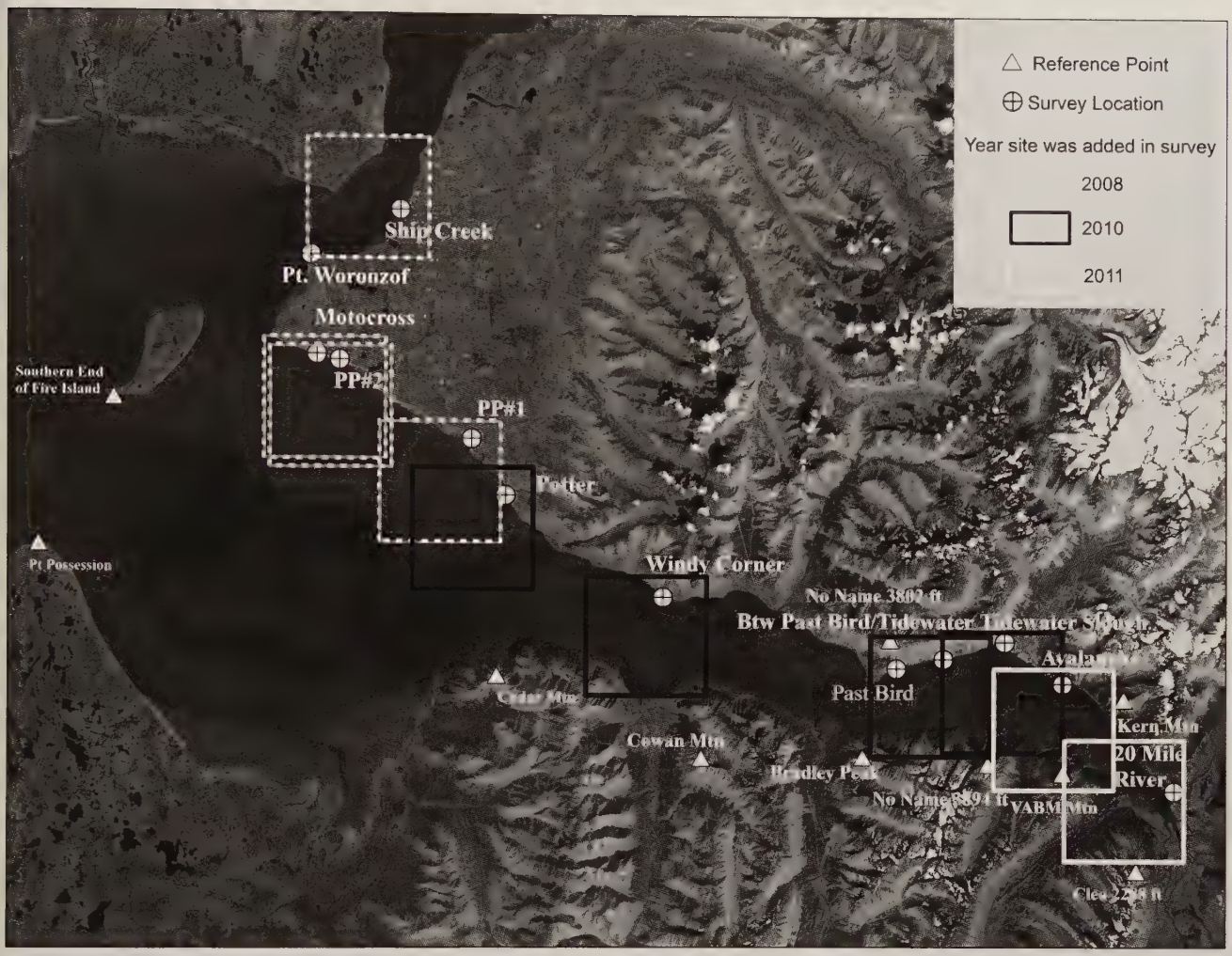

Figure 1.—Dedicated ACBS Sites: Ship Creek Boat Ramp (Ship Creek), Motocross (MotoX) Bluff, Private Property No. 1 (PP No. 1), Turnagain Arm (TA), Potter Section House (TA Potter), TA Windy Corner (TA Windy), TA first pull-out past Bird Point (TA Past Bird), TA Tidewater Slough (TA Tidewater), TA Avalanche, and TA Twenty-Mile River Boat Launch (TA 20-Mile). Supplemental ACBS Sites: Private Property No. 2 (PP No. 2), Point Woronzof Beach and Bluff (Woronzof Beach/Bluff), and Between Past Bird and Tidewater.

were found to favor medium to fast flowing rivers (Goetz et al., 2007).

Survey Scheduling

FAR scheduled surveys based on what particular data were desired, tides, daylight hours, and the number of trained volunteers available. In addition to crew leaders, two or three additional crew members were required to conduct a survey, and up to six total volunteers were allowed per shift to help individuals get survey experience. FAR sought to schedule surveys around high tides during predicted fish runs which would presumably bring belugas closer to shore and into nearby creeks and rivers where desired information could be recorded. The survey also focused on high tides because the vast majority of aerial surveys conducted by NMFS took place during low tides, so use of this near-shore area (covered with water during high tides) is less well documented (Shelden et al., 2013).

Schedules were created around daylight hours and made use of civil twilight[7] to extend observation time when days were short. This was necessary for safety and set up of equipment. Since fish availability was a consideration, site scheduling took into account neap tides for flatfish (yellowfin sole, *Limanda aspera,* and starry flounder, *Platichthys stellatus*) as well as the timing of anadromous fish runs such as eulachon (or "hooligan"), *Thaleichthys pacificus*, and Pacific salmon, *Oncorhynchus* spp.

Prior to scheduling for survey seasons, FAR reviewed the website host-

[7]Civil twilight is when the sun is between 0° and 6° below the horizon, before sunrise and after sunset, commonly known as dawn and dusk, when it is possible to see because there is sufficient light to see land features.

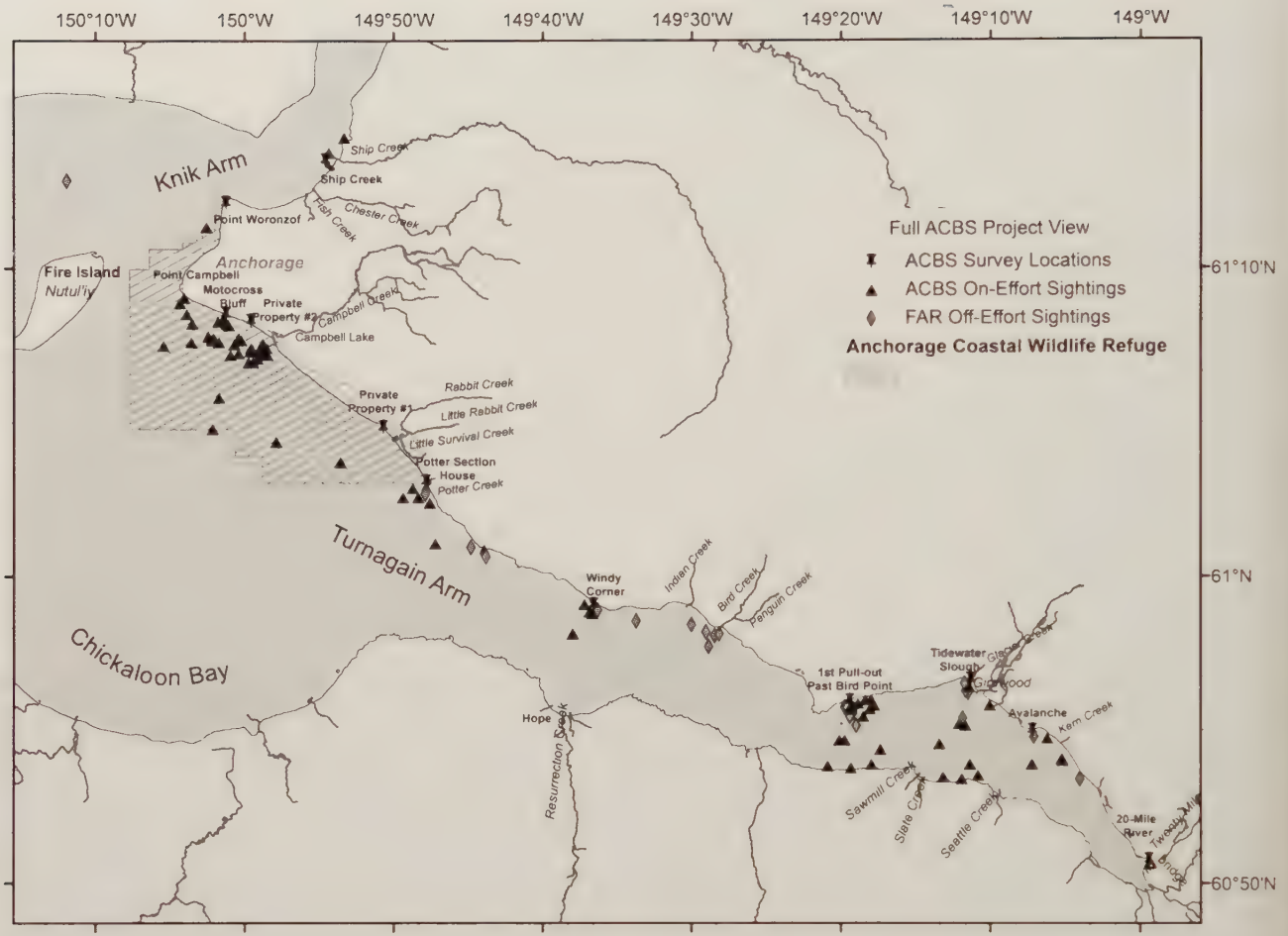

Figure 2.—Overview of Anchorage Coastal Beluga Survey study sites, dedicated, supplemental, and incidental beluga whale sightings, 2008–11.

ed by the Alaska Department of Fish and Game on Sport Fish Run Timing (ADFG[8]). More information on fish run timing was collected by emailing and/or speaking with Fish and Game department biologists regarding differences and clarifications about the project area for which few data are extant (Bosch et al.[9]). Project sites spanned from Ship Creek, near the Port of Anchorage, to Twenty-Mile River, past the town of Girdwood, and fish species, run timing (where applicable), and availability as prey differ somewhat from one site to the next. More on arrival times and places of specific species is given in Švarný Carlson and Brunner.[10]

[8]ADFG. Sport Fish Run Timing. (Anchorage, Matanuska-Susitna Fresh Water Run Timing, retrieved May 2010 from http://www.adfg.alaska.gov/index.cfm?adfg=PersonalUsebyAreaSouthcentralHerringandHooligan.regs and http://www.adfg.alaska.gov/index.cfm?adfg=fishingSportFishingInfoRuntiming.main).

[9]Bosch, D. E., M. Miller, and M. Willette. Alaska Dep. Fish Game biologists. Personal commun. with B. S. Carlson via telephone and email, spring and summer 2011.

[10]Švarný Carlson, B., and S. Brunner. 2012. Observations of Cook Inlet beluga whales, *Delphinapterus leucas*, along the Anchorage coast between 2008 and 2011. Unpubl. rep. submitted by Friends of the Anchorage Coastal Wildlife Refuge, P.O. Box 220196, Anchorage, AK 99522-0196 to Natl. Mar. Fish. Serv., Reg. Off., Anchorage, AK, p. i-227. (avail. online at http://alaskafisheries.noaa.gov/protectedresources/whales/beluga.htm).

Survey Gear

FAR minimized the amount of survey gear required so the project could be sustained at low monetary cost. After consulting with several marine mammal researchers, FAR elected to purchase equipment sturdy enough to survive weather and use by many volunteers, not be prohibitively expensive, and yet of high enough quality to meet project needs. Equipment included binoculars, spotting scope, tripod, data sheets, project maps, copy of the Beaufort Wind Scale (BF) showing both "on water" and "on land" effects, and GPS units. Field gear was stowed and maintained by the project lead and

checked out and in by crew leaders before and after each shift.

Training Citizen Scientists

Training for ACBS crews consisted of a minimum 2.5 h class, assigned reading of the Monitoring Instructions Handbook, and an orientation of survey sites and routes to assist volunteers in locating the designated sites. When possible, returning volunteers took the annual training class, otherwise they read the revisions and worked the first couple of shifts with a leader who had attended the current training session. The training presentation highlighted proper gear set-up including the use and break-down of the project spotting scope and important features of the marine binoculars. Instructors taught participants how to fill out each project form as well as how to use a compass and the Beaufort Wind Scale. For the purpose of the survey, FAR instructed volunteers to count belugas by counting only when they saw "skin" and taught methods of scanning for whales.[11]

Although volunteers were not "tested" while counting belugas, during the rigorous training sessions, participants practiced counting belugas, deciding relative sizes and colors of belugas, and documenting weather conditions shown on slides. As part of documenting beluga groups, FAR asked volunteers to watch for adults with calves and estimate the size of the calf and its proximity to the nearest adult (Litzky, 2001; Hobbs et al., 2015b). FAR also presented an overview of marine mammal species other than belugas that volunteers were most likely to encounter in upper Cook Inlet. On-site orientations were also provided at survey locations for volunteers to practice set up of equipment, familiarize themselves with the sites and landmarks referenced on project maps for optimal beluga placement, and practice scanning for belugas. Open communication with the Primary Investigator (PI) during surveys as well as a conservative approach to identifying whale groups helped increase data integrity, by repeatedly emphasizing the importance of recording as accurately as possible what was observed. Volunteers strove to achieve a consensus of numbers among observers before they recorded those data both to help increase precision and to avoid extreme high or low counts.

The Monitoring Instructions Handbook included a project summary, goals, objectives, the current season's sites, a description of the responsibility of volunteer positions, and a list of equipment required, along with detailed explanation of equipment care. The handbook provided examples of how to complete each form and discussed how to choose from a range of given responses and when to supply written but succinct descriptions. Instructions included an explanation of the scanning protocol (rotation of tasks, what the tasks entailed, a recommendation for how long a rotation should last, specific types of scans to use, and wrap-up tasks for the end of a shift).[11]

Additionally, the handbook provided a prioritized list of tasks should a stranded marine mammal be spotted (dead or alive) ensuring that observers scan purposefully during each shift for stranded marine mammals and be able to call and report the stranding to bring appropriate help to the location as soon as possible.

When scheduling crews and crew leaders, the goal was to have as many returning experienced volunteers as possible to balance crews with known attributes. The opportunity to work with experienced observers provided supervised hands-on training with the exacting tasks required for good data collection and documentation. Crew leaders used volunteers with leadership potential to help with management tasks for the crew, thus preparing volunteers for future roles in lead positions.

Data Collection

Scanning protocols directed observers to alternate scanning for belugas with spotting scope and the naked eye, or binoculars and the naked eye. Observers rotated scanning shifts every 10–15 min to limit observer fatigue and also rotated to data recording for a break, provided they had the requisite training and experience. Scanning methods could vary from scanning from left to right, moving further away from or closer to the horizon, or scanning up and down from the horizon to the shore while moving left to right. A minimum of two observers scanned at the same time during a shift.

Data collection protocols included recording specific start/end times, reporting environmental conditions during the shift, and documenting what observers saw at specific sites during the scheduled times. The shift form documented information that tied beluga sightings, the specific day, site location, time, crew, and environmental conditions (temperature in Celsius, BF, wind direction, precipitation, percentage of cloud coverage, sea conditions, and general viewing conditions); and whether live or stranded (dead or alive) belugas or if other marine mammals were seen during the shift. Volunteers also recorded the presence of other wildlife, human activity (such as dog walkers, motorized land vehicles, boats, and planes), and whether or not a formal oral history interview was conducted.

A beluga form and a map form were used to document each observed beluga group. The beluga form includes the specific site location, the date, the time belugas were observed, and which beluga group the form represents (first, second, third, etc., if more than one group of belugas was observed during that day's shift). The beluga form employed a grid number where the beluga group was spotted initially; and minimum, maximum, and best count of belugas (Funk et al.[12].), including colors,

[11]The ACBS handbook and forms are available in appendices 6.1 through 6.6 of Observations of Cook Inlet beluga whales, *Delphinapterus leucas*, along the Anchorage coast between 2008 and 2011(Švarný Carlson and Brunner, 2012), posted on the NOAA Protected Resources website. https://alaskafisheries.noaa.gov/sites/default/files/cibobservations_2008-2011.pdf.

[12]Funk, D. W., T. M. Markowitz, and R. J. Rodrigues (Editors). 2005. Baseline studies of beluga whale habitat use in Knik Arm, Upper

sizes, and proximity of calf to adult, when possible. Since Cook Inlet belugas are dark gray at birth and slowly change to lighter gray and to white as they mature, the color of individuals in a group can give information of the age classes present (Litzky, 2001; Hobbs et al., 2015a, b). Proximity of smaller dark whales to adult whales was also recorded because proximity of individuals may give insight into age classes (Krasnova et al., 2006; Hobbs et al., 2015a, b)

For data validation purposes, beluga groups were counted independently by separate observers. Although not technically a blind count, discussion of group numbers were usually reserved until all observers were able to count the beluga group multiple times. The final numbers for group size (minimum, maximum, and best) were determined by consensus between the 3–6 observers.

Some citizen science projects include procedures to test the accuracy of species identification and counts. For a Cook Inlet beluga survey, this would likely involve an aerial photograph to compare with a specific sighting count, neither of which was financially or logistically feasible for the survey. Without a way to ground-truth beluga sightings and group sizes, the more experienced or knowledgeable crew leader helped direct identification of species and determination of group size during consensus discussions.

Additionally, the PI made unannounced visits to crews on shifts to help assure data quality, during which time any errors of procedures were corrected on the spot, and notes were taken on issues with protocols. If the PI felt clarification was necessary to supplement the Monitoring Instruction Handbook, an ancillary teaching packet was developed so that the data would be accurately and consistently recorded.

When possible, whale behavioral information was recorded on the beluga form. Since Cook Inlet waters are turbid, any documented beluga behavior was limited to those visible above water. Categories of behavior included feeding (observed or suspected), traveling, diving, resting, milling, (Funk et al.[12]; McGuire and Kaplan[13]), body contact, spy hopping, tail waving, tail slapping, porpoising, vocalizing, and spouting. FAR rewrote descriptions and added to the Photo ID project (McGuire and Kaplan[13]) list of behaviors to meet ACBS needs (Švarný Carlson and Brunner[10]).

Validation of behavior data took place as survey crew members discussed observed surface activities before including detailed comments describing behaviors and surface activities. Behavioral comments also included notes on group composition. Behavior data was further validated when the PI reviewed behavioral comments and discussed any questions with the crew leader. When time permitted, human activities, in particular boat traffic, were also documented with increased emphasis starting in 2012; however; those data are not part of this paper and have yet to be analyzed.

Detailed maps referencing natural features visible from each project site were designed specifically for survey volunteers to plot beluga sightings within the study area accurately with minimal tools (Fig. 3). Reference points enabled observers to orient themselves and whales in the survey area for more precise placement of sightings on the map. This was important because the ACBS did not use a survey tool such as a theodolite to triangulate a beluga's location.

Outside of dedicated survey time, FAR also collected incidental observations of belugas from volunteers and the general public. Although these incidental sightings can add to what can be learned about belugas, incidental reports have incomplete sighting and environmental data and are analyzed separately from dedicated survey reports.

Data Management Post Survey

With help and support from the Alaska Fisheries Science Center's National Marine Mammal Laboratory (NMML) and volunteers, FAR designed, and now maintains, the FAR Fieldwork and Volunteer Database, which is a MS Access 2007[14] database. FAR crew leaders and data managers followed detailed data collection and data entry protocols to ensure data accuracy making the survey information valid and useful data. These procedures, complete with data forms, are given in Švarný Carlson and Brunner[10].

Results

Between 2008 and 2011, ACBS volunteers logged 444 h scanning for belugas on scheduled watches over a total of 348 survey shifts (Fig. 4). Data were collected during at least four different months at five of the project locations (Table 1): 1) Ship Creek (at the small boat launch); 2) MotoX (also known as Kincaid Motocross or Jodhpur bluff); 3) TA Potter (Potter Section House on Turnagain Arm); 4) TA Past Bird (first pull-out past Bird Point on Turnagain Arm); and 5) TA Tidewater (Tidewater Slough on Turnagain Arm).

Seven sites were staffed for less than 4 different months, primarily centered around months in summer and early fall. These included 1) Woronzof Beach/Bluff (at Point Woronzof); 2) PP No. 1 (Private Property No. 1, near the north end of Potter Marsh); 3) PP No. 2 (Private Property No. 2, near Campbell Creek); 4) TA Windy (Windy Corner on Turnagain Arm); 5) Between Past Bird and Tidewater; 6) TA Avalanche (on Turnagain Arm); and 7) TA 20-Mile (near Twenty-mile River on Turnagain Arm). Over the

Cook Inlet, Alaska: July 2004-July 2005. Report from LGL Alaska Res. Assoc., Inc., Anchorage, with HDR Alaska, Inc., Anchorage, for Knik Arm Bridge and Toll Authority, Anchorage, Dep. Transp. Public Facil., and Fed. Highway Admin., Juneau, Alaska, 232 p.

[13]McGuire, T. L., and C. C. Kaplan. 2009. Photo-identification of beluga whales in Upper Cook Inlet, Alaska. Final rep. field activities in 2008. Rep. prep. by LGL Alaska Research Assoc., Inc., Anchorage, AK, for Natl. Fish Wildl. Found., Chevron, and ConocoPhillips Alaska, Inc., 28 p.

[14]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

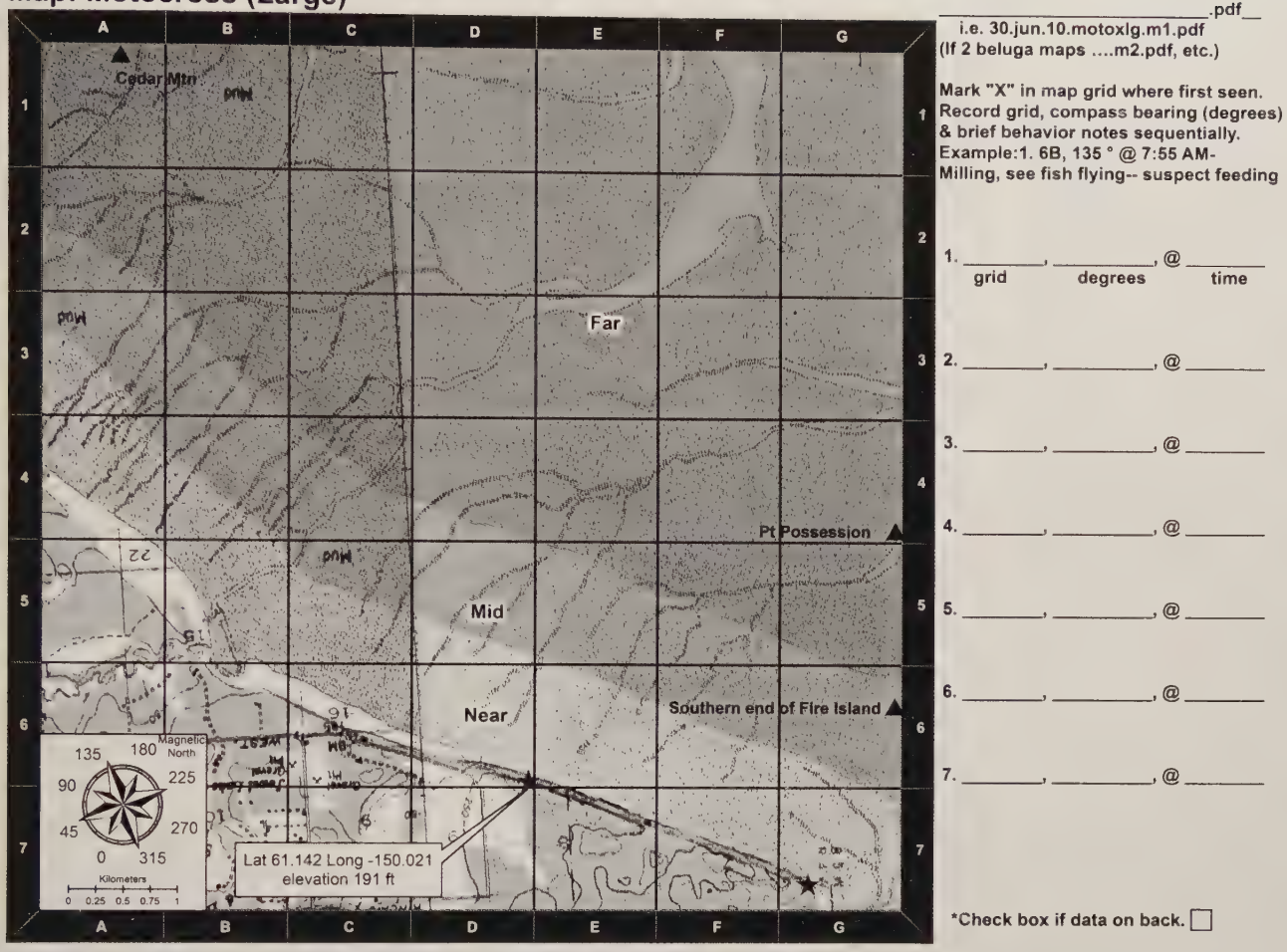

Figure 3.—One example of a map provided for each observation site showing survey area and nearest creeks with a 1 km (about 0.75 mile) grid overlay, and compass rose rotated to magnetic north. Shading divided the water into categories of near-shore, middle distance, and far distance, and showed prominent tidal guts and channels. Triangles on maps represented reference points of natural features viewed outside the map boundaries.

course of 4 years, surveys were scheduled for 175 days, of which 160 were completed; the remainder had been canceled due mostly to inclement weather and poor visibility (Table 2).

Observers counted the number of whales in groups during a survey shift and did not identify individual belugas, so individuals were likely observed multiple times within and across seasons. During the 4-yr project, 77 groups totaling 507 beluga whale sightings were documented; of these, 31 were identified as calves (Fig. 5).

Beluga behaviors were recorded at all sites with observers primarily charting general direction of movement and documenting behaviors listed on data sheets. Milling, porpoising, and spouting were the most commonly observed behaviors. Changes in surfacing behaviors were noted in association with boat traffic and the take-off of an F-15 jet at Ship Creek. Groups of belugas were observed moving in and out of Campbell Creek, exhibiting milling and diving behaviors that suggested feeding. Observers both at MotoX and PP No. 2 documented beluga groups possibly chasing prey, and included a repeated pattern of fast swimming in tidal guts, then movement back into a deeper part of the inlet. During one such observation, the belugas alternated energetic bouts with periods of apparent rest, where the whales would remain mostly submerged for several minutes, then begin spouting and fast swimming again.

Results for individual survey sites varied according to effort expended per location as well as seasonal and tidal scheduling (Fig. 2). The ascending order based on the total counts of belugas by effort hours was PP No. 1 (4.23 h/four belugas); Woronzof Beach/Bluff (low and high vantages) (1.20 h/five belugas, including one calf); Between Past Bird and Tidewater (0.22 h/nine belugas); TA 20-Mile

Figure 4.—Cumulative Anchorage Coastal Beluga Survey beluga-scanning effort and shifts, 2008–11.

Table 1.—List of survey sites with time ranges during each season. Although dedicated beluga data exists for PP No. 2, Woronzof Beach, and one site between Past Bird and Tidewater, they are not included in the time range table because those survey shifts, although complete, were additions to the schedule.

	Survey time span			
Survey site	2008	2009	2010	2011
MotoX	18–22 Oct.	10 June–30 Oct.	10–28 Aug. 5 Sept.–31 Oct.	13 Aug.–28 Sept. 1 Oct.–1 Nov.
PP#1	21–22 Oct.			
Ship Creek	12 Oct.–12 Nov.	9 June–30 Oct.		
TA Potter			5 Sept.–31 Oct.	8–22 May 13 Aug.–28 Sept.
TA Windy			5 Sept.–31 Oct.	8–22 May 13 Aug.–28 Sept.
TA Past Bird			5 Sept.–31 Oct.	8–22 May 13 Aug.–28 Sept. 1–31 Oct.
TA Tidewater			5 Sept.–31 Oct.	8–22 May 1–31 Oct.
TA Avalanche				8–22 May 1–31 Oct.
TA 20-Mile				8–22 May 1–31 Oct.

Table 2.—Number of days surveyed per season from each Project site. Table illustrates the number of days that ACBS crews completed shifts at each observation site per season; the number of shifts scheduled per site per season; the days scheduled for the survey per season; the days with complete shifts (that were not cancelled) per season; and totals.

ACBS Observation Site	Pre-survey	2008	2009	2010	2011[1]	Totals	Total seasons
PP#1	0	2				2	1
PP#2	ne[2]	ne	ne	ne	8	8	>4
MotoX	ne	5	50	29	22	106	>4
Ship Creek		5	42			47	2
TA Potter				18	22	40	2
TA Windy				18	22	40	2
TA Past Bird				18	29	47	2
Between PastBird/Tidewater				1	0	1	2
TA Tidewater				18	15	33	2
TA 20-Mile					7	7	1
TA Avalanche					8	8	1
Woronzof Beach/Bluff					1	1	1
Total complete ACBS shifts		12	92	102	134	340	
Number of shifts scheduled		12	105	106	150	373	
Days With Complete shift		10	81	28	41	160	
Days scheduled		10	89	30	46	175	

[1]Project lead spot data entered for 2011.
[2]ne=not entered.

(3.22 h/10 belugas, including one calf); Ship Creek (94.53 h/13 belugas); TA Windy (19.08 h/15 belugas, including two calves); TA Avalanche (6.32 h/23 belugas); TA Tidewater (20.03 h/26 belugas, including one calf); TA Potter (21.17 h/33 belugas, including three calves); PP No. 2 (9.30 h/83 belugas, including five calves); TA Past Bird (29.21 h/84 belugas, including two calves); and MotoX (260.18 h/202 belugas, including 16 calves) (Fig. 6). The number of whales seen within the ACWR was 36% higher than areas outside of the ACWR with 310 whales seen within the ACWR and 197 whales seen outside the refuge (Figs. 2, 6).

Human activity was documented on 209 shifts over the course of the survey period. Instructions for observers allowed leeway regarding what potential human impacts were documented, so that we did not miss something that might be important later that could impact the health or behavior of belugas. Volunteers were asked to look during surveys for pollution, trash, pet use and deposition of fecal matter, and loud noises and their sources. Documented human activity during surveys ranged from windsurfers to construction noise (Fig. 7). The MotoX site had 81 shifts documenting human activity out of a total of 106 shifts, most of which were dirt bike noises, airplane traffic from the nearby airports and lakes, as well as hunters or other people on foot. The Ship Creek site had 46 shifts (out of a total of 54) with human activity noted, most of which was fishing, boats, tugs, or dredges and construction activities near the Port of Anchorage. Turnagain Arm sites run along the road and had 78 shifts with human activity noted, most of which was vehicular traffic along with some roadside tourist activity, windsurfing, kayaking, and fishing activities.

The survey included a form to record germane oral histories, but managers found there was insufficient time for volunteers to follow through. Depending on the popularity of the survey site and the presence of other visitors, providing an opportunity to

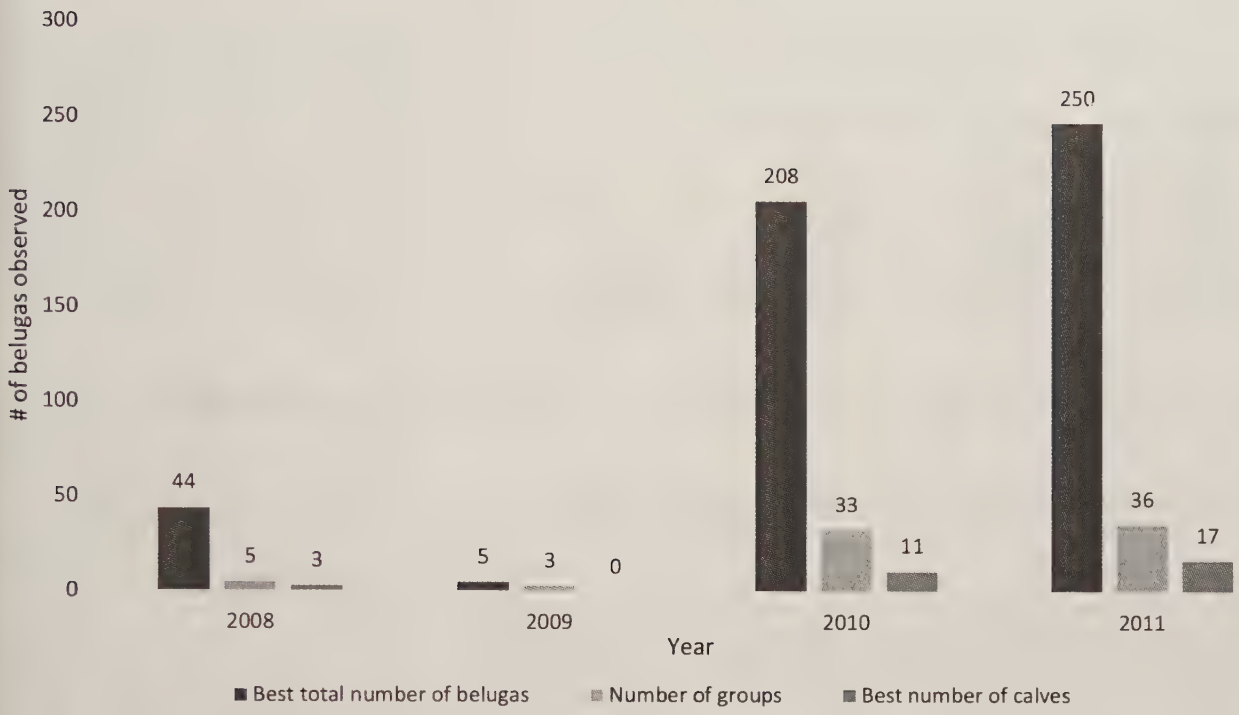

Figure 5.—Number of belugas observed on-effort by Anchorage Coastal Beluga Survey volunteers, 2008–11. Total individual dedicated and supplemental beluga sightings throughout project.

help educate the public as well as solicit local beluga knowledge at times would have taken time away from scanning and documenting belugas, if allowed. Crew leaders reminded volunteers of the priority order to scan and record data first, and usually there was no time to solicit oral history information. The interest in what might be learned from oral histories centering around belugas was significant enough to merit a separate project, which was undertaken by the Alaska Sealife Center for the Kenai Peninsula Borough, dedicated to Cook Inlet beluga work in that area (Dutton et al.[15]).

Over the course of 4 yr, the numbers of volunteers increased annually (Fig. 8). Volunteers for the ACBS logged 444 observation hours at 12 survey sites along the Anchorage coastline. A combined total of FAR on-effort observations and incidental sightings over 4 yr yielded 680 beluga whale sightings, in 106 groups, of which 43 of the whales sighted were identified as calves. Throughout the study, FAR trained 208 volunteers of which 153 followed through to assist with gathering beluga data. There was a 59% increase in project personnel in 2009 after the first pilot study year in 2008 and then a 15% increase in volunteer personnel in 2010 and a 17% increase in 2011. A number of other residents responded with interest every year who were unable to participate because they could not make the training sessions.

In 2008, FAR and Defenders of Wildlife (DoW) trained 26 volunteers with 19 following through to staff shifts; this was the pilot year and 11 of those completed two or more shifts. In 2009 the partnership trained 50 volunteers with 44 following through to staff shifts; 33 of those helped with three or more shifts. In 2010 FAR trained 61 volunteers with 52 following through to staff shifts; 30 of those completed three or more shifts. For 2011, the last survey year included in this paper, FAR trained 71 volunteers with 58 following through to staff shifts; 44 of those helped with three or more shifts. Between 2008 and 2011 eight guests helped with minor survey tasks under supervision of trained volunteers. Over the course of the 4 years of the survey, the total number of shifts increased and the level of effort hours were maintained above 100+ h each season after the initial pilot survey season in 2008 due to the number of dedicated trained volunteers (Fig. 9).

Although new volunteers made up the base of the total number each year, a core group of returning volunteers helped round out the observer pool. Volunteers that attended training but were unable to participate in 3 or more survey shifts were counted separately from the main pool of volunteers but were included in the total number of

[15]Dutton, I. M., J. R. Klein, K. J. Cain, R. Deel, R. Federer, H. LeBail, and J. Hunt. 10 May, 2012. An oral history of habitat use by Cook Inlet belugas in waters of the Kenai Peninsula Borough. Final Rep. Prep. for the Kenai Peninsula Borough. http://www.alaskapublic.org/wp-content/uploads/2012/06/3-R0086-Oral-History-of-CIBW-Final-Report-FINAL-051012.pdf

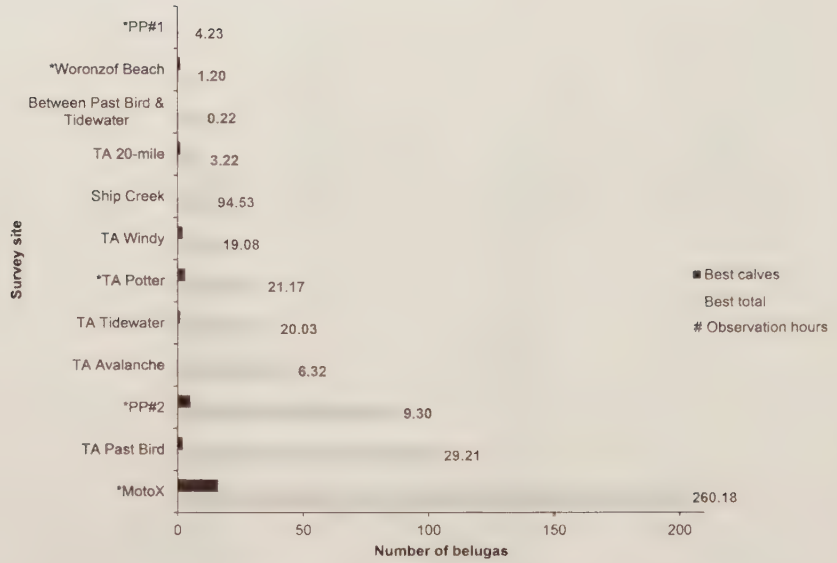

Figure 6.—Number of belugas observed at each Anchorage Coastal Beluga Survey project site 2008–11 (Numbers after bars indicate total observation hours for each survey site. Asterisk next to site name denotes sites located within the ACWR).

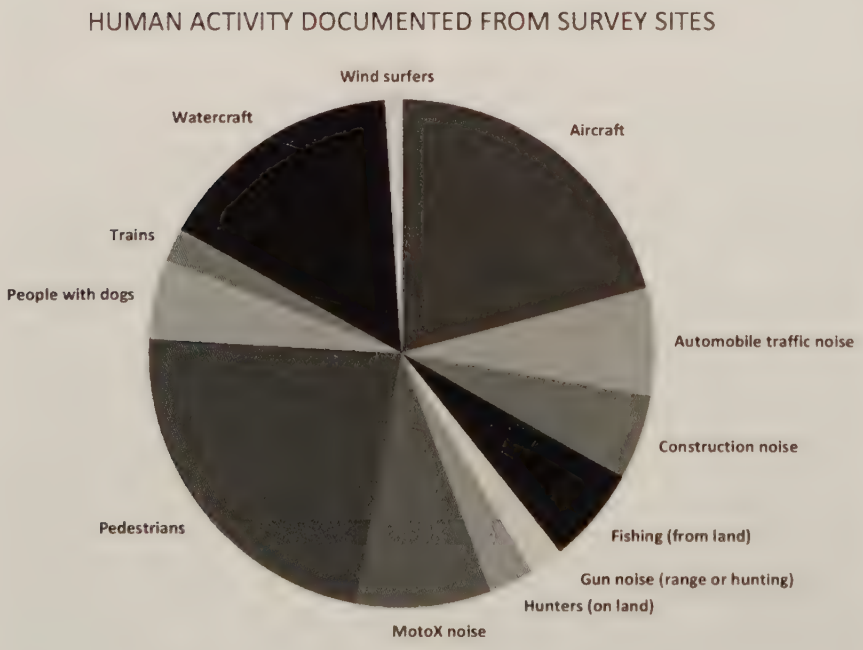

Figure 7.—Human activity documented from survey sites.

volunteers trained each season. The average number of shifts per volunteer was 1.7 shifts per volunteer in 2008, 6.5 shifts per volunteer in 2009, 3.9 shifts per volunteer in 2010, and 4.9 shifts per volunteer in 2011. Although many volunteers only worked one shift each year, a core group volunteered for 3 or more shifts with several individuals working 10 or more shifts in the 2009–2011 surveys (Fig. 9).

Discussion

Since FAR undertook no in-depth analysis of data collected during the ACBS, discussion will focus on interesting issues noted from the summarization of the data. In-depth analyses in collaboration with interested professional scientists are possible in the future.

The MotoX site was the only one surveyed all 4 yr, due to its importance as an overlook of the ACWR and its proximity to Campbell Creek, Fire Island, and the physical center of FAR's stewardship efforts. The MotoX site has also been used by the organization for several projects. Conversely, the Ship Creek site was only used during 2008–09 because FAR management believed that better data were being gathered by the well-funded port-monitoring project through Alaska Pacific University (Kendall and Cornick, 2015; Pinney and Cornick[16]; Cornick and Saxon[17]; Cornick et al.[18]). Further, the Ship Creek site manager was

[16]Pinney. L. and L. Cornick. Assessing relationships between beluga whale habitat use, prey availability, and hydrodynamics in the Knik Arm of Cook Inlet, Alaska, unpubl. manuscr.

[17]Cornick, L. A., and K. L. Saxon. 2008. Distribution, habitat use, and behavior of Cook Inlet beluga whales in Knik Arm, fall 2007. Unpubl. rep. to Integrated Concepts and Research Corp., Anchorage, 28 p. Avail. at Integrated Concepts and Research Corporation, 421 West First Avenue, Suite 200, Anchorage, AK 99501 (retrieved 15 Mar. 2012 from http://www.fakr.noaa.gov/protectedresources/whales/beluga/development/portofanc/apu_cib_habitat_07.pdf).

[18]Cornick, L. A., L. S. Kendall, and L. C. Pinney. 2010. Distribution, habitat use and behavior of the Cook Inlet beluga whales and other marine mammals at the Port of Anchorage Marine Terminal Redevelopment Project, May-November 2009. Scientific Marine Mammal Monitoring Program 2009 Annual Report. Prep. for U.S. Dep. Transportation Marit. Admin., Port of Anchorage and Integrated Concepts and Re-

no longer available to help, other partner organizations declined, and the additional administrative load for FAR was unwieldy, making it an easy decision to focus efforts on other locations. The addition of more Turnagain Arm survey sites in 2010 added a new challenge to scheduling, but the new locations gave much-needed insights into use of Turnagain Arm by belugas, with over 200 whales sighted.

The number of beluga sightings recorded at MotoX during 2009 were significantly below those seen in subsequent years. No whales were documented at the site during surveys in June, July, and October, despite logging over 55 h of observation time. One variable of note was that during July through October, NMML requested that FAR schedule blindly, regardless of neap tides or conditions that would increase the chance of seeing belugas (Hobbs[19]). Another variable related to the fact that the number of days in which boat traffic was documented at the MotoX site was greatest during 2009, with 6 days recorded as having boat traffic present, twice the number recorded for years 2010 and 2011 combined. Other than the 2009 blind scheduling (regardless of neap tide cycle) at MotoX, and where Ship Creek was scheduled around low tide, the 2008, 2010, and 2011 surveys were scheduled based on high tides when belugas were expected to be in the area.

The Ship Creek observation site ranked second highest in number of effort hours (94.52 h), but it had the fifth lowest ranking in whales sighted (13 whales). Again, during 2009 July through October, as at the MotoX site, FAR scheduled Ship Creek surveys regardless of the neap tidal cycle. At Ship Creek, in 2008, there was one beluga group of 15 whales sighted at high tide in comparison to the 2009 sighting of one whale during low tide. Ship Creek observers recorded significantly greater boat traffic at this site compared to other observation sites. However, because the 2009 survey times at the Ship Creek site were centered around low tide, as requested by T. McGuire[20], further study would be required during high tide when we expect belugas to be present, to ensure a better measure of beluga occurrence for that site and if boat activity was having any impact.

With ongoing development around Fire Island, FAR management understands that it would be particularly useful to have more data on belugas traversing the narrow passage of water between the northern tip of Fire Island and Point Woronzof Beach/Bluff and Point Campbell (Mahoney[21]). Observations from both PP No. 2 and the MotoX survey sites provided some data near Fire Island, including instances of belugas apparently chasing abundant prey, for example eulachon or salmon into the tidal guts repeatedly. Point Campbell is a high bluff, clos-

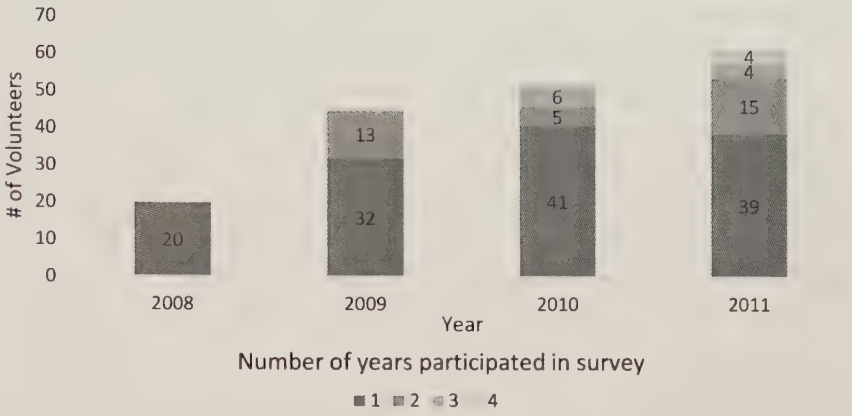

Figure 8.—Number of volunteer observers each year color shaded based on number of years assisting in the survey.

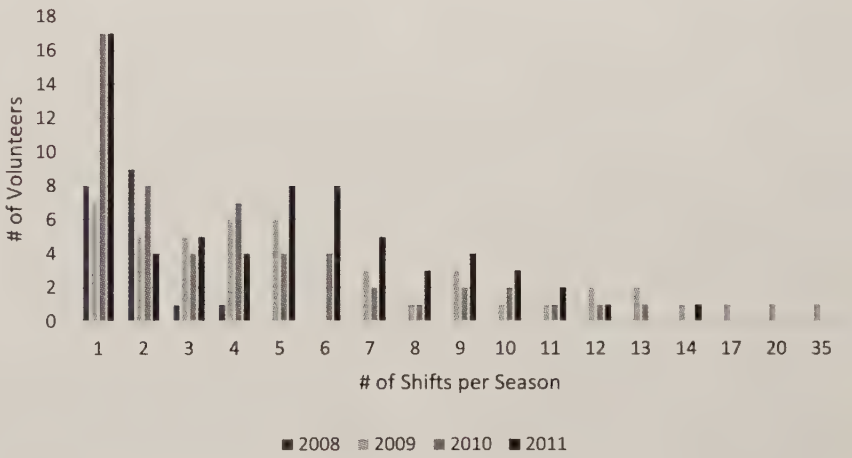

Figure 9.—Number of shifts per volunteer each year.

search Corporation. Prep. by Alaska Pac. Univ., Anchorage.

[19]Personal commun. between Rod Hobbs (NMML) and B. S. Carlson, June 2009.

[20]Personal commun. between Tamara McGuire (LGL) and B. S. Carlson, April 2009.

[21]Personal commun. between Barbara Mahoney (NMFS Alaska Reg. Off.) and B. S. Carlson, May 2010.

er to Fire Island, and a better site from which to document beluga use of the Fire Island area. The Point Campbell site was used to survey the waters between Fire Island and the Kincaid area for nearly 8 mo by 61 North Consulting, LLC, for Cook Inlet Region, Inc. (CIRI). A report was recently released via the NMFS Protected Resources website documenting the study of belugas between ACBS sites just east of the Point Campbell site, an area with many tidal guts (Brueggeman et al.[22]). More observation at Point Campbell documenting belugas from the high vantage location, with more powerful optics than the CIRI survey team had available could provide valuable insight into beluga activities in the vicinity.

FAR reduced the potential for observer bias by the use of experienced leaders, through extensive training, the use of multiple individual counts, followed by consensus determining the final group size count, and descriptions of belugas observed. There was little emphasis on color because project leads recognize that the variation in light would make describing beluga colors unreliable. Training sessions utilized the use of photograph slides of belugas taken from land at a distance, from different angles, in different sea states, and in different lighting. Instructors emphasized the difficulty and the importance in making a quick assessment of what one observed so that it could be documented. This required when belugas were sighted that as many crew members as possible focus on counting the belugas multiple times before comparing notes for consensus, in order to reduce the likelihood of biases.

Further study of the occurrence of belugas may be warranted in areas undergoing significant development. With increasing development, there is concern that increases in human activity, such as increased number and size of vessels and increased amounts of construction activity, may have a negative impact on habitat use by the Cook Inlet belugas (Kendall et al., 2013; Norman et al., 2015). Increased human activity could also increase the amount of background noise that may mask acoustic signals and inhibit the capacity of marine mammals to communicate, forage, navigate, and avoid predators (Miller et al., 2000; Croll et al., 2001; Foote et al., 2004; Norman[23]). Noise could also have implications on breeding and social cohesion and in response to noise, marine mammals have been observed to decrease or cease vocalizations for weeks or months (Weilgart, 2007). Kendall et al. (2013) observed a decreasing trend in the hourly click rates of Cook Inlet belugas at the Port of Anchorage Marine Terminal Redevelopment site, between times without and with construction activity, a possible indication of disturbance. Additionally, an increase in noise levels has the potential to damage marine mammal hearing temporarily and permanently (Schlundt et al., 2000).

Many animals produce louder, longer, or more repetitious vocalizations to compensate for increases in environmental noise (Parks et al., 2011; Holt et al., 2015). Further, Holt et al. (2015) found that an increase in vocal effort between captive common bottlenose dolphins, *Tursiops truncatus*, created an increase in metabolic rate and oxygen consumption over a resting period that followed sound production in both animals, and that the metabolic cost may add up over time when the individuals must compensate for chronic background noise. A similar metabolic effect may be of concern for Cook Inlet belugas, particularly with an increase in ambient noise levels due to increases in shipping and construction activity.

Lusseau et al. (2009) found that vessel traffic may have contributed to southern resident killer whales, *Orcinus orca,* becoming endangered, by causing changes in behavior including a reduction in time spent foraging. Results from studies in Glacier Bay, Alaska, show four documented incidents of humpback whales, *Megaptera novaeangliae*, being awakened by cruise ship wakes (Neilson et al., 2013). In all cases, the whales dove, but it is critical to note that whales may not always wake up when a boat approaches and sometimes may be hit and injured or killed (Neilson et al., 2013). During observations of Cook Inlet belugas, Stewart[24] documented that small boats, such as inflatable, skiff, and hovercraft, caused belugas to respond (e.g., diving, speeding transit, leaving area) depending on proximity of said watercraft, how long they were near belugas, and activity. Stewart[22] also suggested that mouths of rivers and creeks may be important for belugas regrouping and socializing as they seem to vocalize there and that recreational or commercial boat noise could disrupt these important beluga transit activities. The effect of boat traffic on beluga whales in and around areas they inhabit may benefit from further study, particularly if there is a possibility that critical beluga behaviors are being negatively impacted by boat traffic (Norman et al., 2015), such as may be the case in Cook Inlet.

The ACBS has increased public awareness of Cook Inlet belugas and their habitat through educating volunteers and, in turn, the trained volunteers educating the public, friends, and family. The increased outreach by FAR, Alaska Center for the Environment, and DoW expanded the number

[22]Brueggeman, J., D. Lenz, and M. Wahl. 2013. Beluga whale and other marine mammal occurrence in upper Cook Inlet between Point Campbell and Fire Island, Alaska August–November 2011 and April–July 2012 (retrieved 23 March 2016 from https://alaskafisheries.noaa.gov/sites/default/files/2013_cib_monitorsurvey.pdf).

[23]Norman, S. A. 2011. Anthropogenic and environmental stressors in Cook Inlet beluga whales (*Delphinapterus leucas*). Literature review and assessment. Rep. prep. for Natl. Mar. Fish. Serv., NOAA, Anchorage, Alaska. NMFS contract no. HA133F-10-SE-3639 (retrieved 15 Mar. 2012 from http://marine-med.com/studies/publications/Norman-2011-Anthropogenic-Environmental-Stressors-Cook-Inlet-Beluga-Whales.pdf).

[24]Stewart, B. S. 2010. Interactions between beluga whales (*Delphinapterus leucas*) and boats in Lower Knik Arm, Alaska: behavior and bioacoustics. *In* NMFS 2010. Cook Inlet beluga whale science conference: agenda and abstracts, p. 10–11. (1 Aug.–14 Sept. 2008) (retrieved 15 Mar. 2012 from http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/acoustics/hswri_techrpt_boats_belugas2012.pdf).

of volunteers who wanted to participate in the survey. Over the 4 years of this portion of the survey FAR and associates trained 208 volunteers, 153 of them helped log 444 observation hours at 12 survey sites along the Anchorage coast. This effort provided an oversight for marine mammal strandings, the documentation of belugas, and scheduled citizen scientists visibly located at selected overlooks. The survey provided a noticeable stewardship presence. During the last 2 years of the survey, the PI would occasionally get phone calls and emails from people saying that they saw FAR's beluga survey volunteers out along Turnagain Arm, often with interested passers-by. FAR, DoW, and NMFS receive notes of interest about belugas from as far away as Colorado and Belgium.

Over the years, citizen science has grown to address ecological questions on scales that are either too large a scale to be addressed only by professional scientists or on smaller local scales that are too restricted for professional scientists (Miller-Rushing et al., 2012). Dickinson et al. (2012) lists various uses for citizen science by professional ecologists ranging from areas of research such as landscape ecology and climate change to finding rare organisms, tracking movements, and detecting species declines.

The FAR beluga survey focused on documenting beluga activities along the Anchorage coastline and compiling data as a reference source for other professional science users. Beluga sighting information with numbers, locations, and data from the ACBS are being used in Section 7 consultations for Seward Highway MP 75–90 repairs and construction and other projects around Turnagain (under the U.S. Endangered Species Act) by permitting offices at the NMFS Alaska Regional Office. Additionally, if NMFS considers a biopsy study of Cook Inlet belugas in Turnagain, the survey data will be used, along with LGL sightings, to help schedule timing of the new study. For any permitted activities that would occur in Turnagain Arm up to Point Woronzof, where an ESA consult is needed, survey data that is not >10 yr old will be used.

Once the survey data is added to the Alaska Ocean Observing System database, it will be made available to others as projects, seasons, timing, and locations are designed. NMFS will continue to use the survey data along with additional data provided by NMML, as using multiple sources of sightings yields more information on Cook Inlet beluga presence (Mahoney[25]). ACBS data were used by the Cook Inlet Beluga Photo-ID project, which looked at seasonal and spatial patterns of beluga sightings documented to see if the sightings matched with the patterns that the Photo-ID project had demonstrated and to make sure that project planners were not missing any hotspots when planning surveys (McGuire[26]).

Conclusions

People have long observed beluga whales offshore along the 16-mi ACWR, usually during the ice-free months of the year (Carlson[27]). Adult and young whales move freely along the shore and up into some nearby rivers and creeks, and feed near the Campbell Creek estuary (Carlson[28]). The proximity of the refuge to Anchorage, Alaska's largest city, makes it an important place for public education and enjoyment, but it also makes the refuge, and its wildlife, vulnerable to the effects of habitat degradation and disturbance. The sharing of relevant local knowledge and concern for the wellbeing of belugas by observant citizens helped create the initiative for the survey.

Volunteers from Anchorage and surrounding towns demonstrated great interest in the status of the beluga whale through their willingness to dedicate time to training, staffing survey shifts, managing project gear, survey associated travel, and helping with both data entry and data checking. Even those who did not participate in the survey itself gained knowledge after attending training sessions and FAR believes this exposure added to an increased constituency for the endangered Cook Inlet beluga whale.

Public engagement with the ACBS made citizens more cognizant of the Cook Inlet beluga status, and more aware of actions that may impact the recovery of this distinct genetic population of belugas. Citizens concerned with the status of Cook Inlet belugas and the health of their habitat may be more willing to participate in conservation measures such as paying more taxes to help upgrade wastewater sewage treatment, conserving natural resources, limiting use of household chemicals that might be contributing to the pollution of Cook Inlet waters, and dumping less pet waste into local creeks and streams that empty into Cook Inlet.

While it may be coincidental that few or no belugas were observed when boats were seen, it is possible that certain boat activity and/or noise affects the presence, numbers, or surfacing behavior of belugas in the same vicinity. It is equally possible that when belugas were being documented, observers were distracted from noticing and recording the presence of boats in the areas. Further accumulation of boat and beluga data, and subsequent analyses, may shed light on this phenomenon. In 2012 FAR changed its protocols to ensure that both belugas and boats in the project area are carefully monitored, but, for 2008-11 we do not have sufficient data to make a statement.

FAR and its partners have worked steadily towards the goal of gathering information on the occurrence, presence, absence, color, numbers, and behavior of belugas along the Anchorage coast, and creating an archive of data for reference purposes by professional scientists. Additionally, data have included information on relative size of calf to adult beluga, when pos-

[25]Personal commun. between Barbara Mahoney (NMFS Alaska Reg. Off.) and B. S. Carlson, Apr. 2014, Aug. 2015, and Dec. 2015.

[26]Personal commun. between Tamara McGuire (LGL) and B. S. Carlson, Apr. 2014.

[27]Carlson, B. S. (FAR), Personal commun., 2011.

[28]Carlson, B. S. (FAR), Personal observ., 2011.

sible. Through this survey, FAR has been able to collect vital information on Cook Inlet belugas and share it with NMFS, ADFG, and others interested in the science and conservation of Cook Inlet beluga whales.

Through the survey, FAR strove to collect the best information about belugas along the Anchorage coast, while creating an engaging and rewarding experience for participating citizen scientists. Sustaining volunteer participation is critical to the success of the survey and must be considered when planning further survey seasons. FAR continually assesses the needs of the refuge that they steward and hopes to be able to include opportunities for citizens to contribute to the Cook Inlet beluga science database again in the future.

The 2012 data has not yet been analyzed, and while FAR is interested in continuing to collect beluga data, the necessary volunteer effort required to start up and manage the survey represents a huge endeavor for such a small organization. If agency and volunteer interest remains high, FAR may seek funds and partners to build on our survey efforts and continue to collect and move forward with a more in-depth analysis. To continue with the survey, FAR will need partners who are willing to work closely with FAR and be able to, competently and diligently, help with higher-level needs, such as site management, scheduling, equipment management and care, and data quality assurance. Alternately, FAR might be willing to advise others seriously interested in taking on a similar project.

Acknowledgments

We are grateful to the many people who contributed to the success of this project. Partial funding for this wildlife survey came from National Marine Fisheries Service Community Outreach through NMFS Enforcement, FAR, Defenders of Wildlife, and Alaska Center for the Environment. We especially thank Roderick Hobbs and staff at the National Marine Mammal Laboratory in Seattle, Les Cockreham with the NMFS Enforcement Division, and Barbara Mahoney and staff with NMFS Alaska Regional Office. Together they have been invaluable in helping Friends of the Anchorage Coastal Wildlife Refuge to connect with appropriate colleagues and manage the data we gather.

We are indebted to the 150 volunteers who came from Chugiak, Eagle River, Palmer, Girdwood, Indian, and Anchorage to staff shifts and perform other project tasks. In addition to the FAR Board, we thank partners Karla Dutton, with Defenders of Wildlife; Toby Smith, formerly with the Alaska Center for the Environment; and the Center's GIS specialist, Doug Tosa; and Michael Carlson, with McCool/Carlson/Green, Architects, Inc. We thank Kim Shelden at NMML for her dedication and expertise with reviews to hone this paper. We also thank the many professionals from whom FAR sought and received collaborative help at the conception of the survey design, some already mentioned above. We are grateful to all of these and other early cooperating and/or supportive individuals, organizations, and agencies and a complete list of acknowledgements and participants can be found in Švarný Carlson and Brunner[10].

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Errata

Howe, M., M. Castellote, C. Garner, P. McKee, R. J. Small, and R. Hobbs. 2015. Beluga, *Delphinapterus leucas*, ethogram: A tool for Cook Inlet beluga conservation? Marine Fisheries Review 77(1):32–40.

The paper inadvertently states in the first sentence of the Abstract (p. 32) and the first sentence of the Discussion section (p. 36–37), that it presents the first peer-reviewed ethogram of wild belugas. The paper does present the first peer-reviewed ethogram of Cook Inlet beluga whales; however, the first ethogram of wild belugas was developed by Smith et al., 1994, and that citation is added to the Appendix on page 40:

Beluga whale (*Delphinapterus leucas*)

Smith, T. G., M. O. Hammill, and A. R. Martin. 1994. Herd composition and behaviour of white whales (*Delphinapterus leucas*) in two Canadian arctic estuaries. Bioscience 39:175–184.

Editorial Guidelines for the *Marine Fisheries Review*

The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to the *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700 (available from the SPO website).

Manuscripts must be double-spaced throughout, and a complete manuscript normally includes a title page, a short abstract, text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

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Keep titles, headings, subheadings, and the abstract short and clear. Because abstracts are circulated by abstracting agencies, it is important that they represent the research clearly and concisely. Headings within each section must be short, reflect a logical sequence, and follow the rules of multiple subdivision (i.e., there can be no subdivision without at least two items).

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The entire text should be intelligible to interdisciplinary readers; therefore, all acronyms, abbreviations, and technical terms should be spelled out the first time they are mentioned. The scientific names of species must be written out the first time they are mentioned; subsequent mention of scientific names may be abbreviated. Follow the U.S. Government Printing Office Style Manual (2008 ed.) and the Scientific Style and Format: the CSE Manual for Authors, Editors, and Publishers (2014, 8th ed.) published by the Council of Science Editors.for editorial style, and the most current issue of the American Fisheries Society's Common and Scientific Names of Fishes from the United States and Canada for fish nomenclature. Only journal titles, scientific names (genera and species), and vessel names should be italicized. Dates should be written as follows: 11 November 2013. Measurements should be expressed in metric units, e.g., metric tons as (t); other equivalent units may also be listed in parenthesis. Common abbreviations and symbols such as mm, m, g. ml, mg, and °C (without periods) may be used with numerals. The numeral one (1) should be typed as a one, not as a lower-case el (l). Write out the numbers zero through nine unless they form part of measurement units (e.g., nine fish but 9 mm).

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Tables should be printed separately and double-spaced. Tables should not be excessive in size and must be cited in numerical order in the text. Headings should be short but ample enough to allow the table to be intelligible on its own. All unusual symbols must be explained in the table heading. Other incidental comments may be footnoted with Arabic numerals. Because tables are typeset, they need only be submitted typed and formatted, with double-spaced legends. Zeros should precede all decimal points for values less than one. Table headings and format should be consistent; do not use vertical rules.

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